Final Report

Evaluation of the Effects of Alternative Diesel Fuel Formulations on Exhaust Emission Rates and Reactivity

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Executive Summary

Over the past several years there has been increased interested in the development of reformulated and alternative diesel fuels to control emissions and provide energy independence. Two fuels that have received considerable attention recently as potential alternative fuels for diesel engines are biodiesel and Fischer-Tropsch (F-T) diesel. These fuels can be derived from renewable sources, can be substituted for traditional diesel with little or no engine modification, and, in the case of biodiesel, have been the beneficiary of legislative initiatives promoting their use. To date, several studies have shown that biodiesel and F-T diesel can provide emissions reductions relative to standard diesel. Much of this work, however, has focused on comparisons with Federal diesel rather than California diesel.

The present program was designed to further investigate the effects of alternative diesel fuels on exhaust emission rates and reactivity in comparison with California reformulated diesel (RFD). In this project, California RFD was compared with biodiesel, an 80/20 (RFD/biodiesel) blend, and a F-T diesel fuel for emissions performance. Chassis dynamometer tests were performed on four vehicles using each of the four fuels. For these tests, emissions measurements were collected for regulated gaseous emissions and particulate matter. Additional measurements were performed to provide chemical characterization of the exhaust particulate including elemental and organic carbon, ions and trace elements and metals, identification of semi-volatile and particulate phase PAHs, and speciation of gas phase hydrocarbons and carbonyls.

The effect of fuel on gaseous and particulate emission rates varied depending on the pollutant and vehicle, as shown in Table ES-1. For the biodiesel and biodiesel blend, particulate emission rates were slightly higher for two the test vehicles and significantly higher for a third test vehicle. While very repeatable over replicate tests and different test periods, the trend of significantly higher PM emissions on alternative fuels for one of the test vehicles may indicate that this vehicle is not representative of the overall light heavy-duty vehicle fleet. Particulate emissions for the F-T fuel were higher for two of the test vehicles and lower for one of the test vehicles.

Table ES-1. FTP Weighted Emissions Results for Diesel Vehicles on Different Fuel Blends

	1996 Dodge Ram 2500				1995 Ford F350				1990 Dodge Ram 250				1988 Ford F250			
	THC g/mi	CO g/mi	NO_x g/mi	Parts mg/mi	THC g/mi	CO g/mi	NO_x g/mi	Parts mg/mi	THC g/mi	CO g/mi	NO_x g/mi	Parts mg/mi	THC g/mi	CO g/mi	NO_x g/mi	Parts mg/mi
RFD	0.419	1.539	8.489	71.9	0.603	2.230	6.359	74.6	0.930	2.093	6.442	193.3	0.334	1.457	6.369	353.2
Bio-Diesel	0.254	1.433	8.304	64.4	0.201	1.720	6.450	106.7	0.738	2.269	7.012	828.1	0.314	1.282	7.054	434.1
80/20 Blend	0.331	1.418	8.315	59.3	0.480	1.895	6.126	98.7	1.111	2.194	6.303	467.9	0.305	1.378	6.393	401.1
Fisher-Tropsch	0.398	1.471	8.210	81.0	0.387	1.984	6.521	53.4	0.868	2.011	5.803	282.4	0.298	1.363	6.367	397.3

THC emissions were generally lower for the neat biodiesel, the biodiesel blend, and the F-T diesel compared with the RFD. The 100% biodiesel had the lowest overall THC emissions: considerably lower than those for the other fuels for all vehicles but the 1988 Ford F350. CO emissions were significantly lower for the alternative fuels for the 1995 Ford, and slightly lower for the 1988 Ford and 1996 Dodge. Higher CO emissions were observed, however, for the biodiesel and biodiesel blend over the 1990 Dodge. NO_x emissions for the alternative fuels and RFD were comparable for the two newest vehicles, the 1995 Ford and 1996 Dodge. Slightly higher NO_x emissions were recorded for the 1990 Dodge and 1988 Ford on 100% biodiesel, while the F-T fuel was slightly lower for the 1990 Dodge.

HC speciation data were obtained for C_1-C_{12} for the 1988 Ford and the 1990 Dodge and C_8-C_{20} for the 1988 Ford. The C_1-C_{12} HC speciation profiles for the 1988 Ford showed little difference among emissions for the different fuel types, except for benzene. The emissions of benzene for the F-T and the 100% biodiesel fuels were about one third and one half, respectively, of the percentage emitted by RFD. For the 1990 Dodge, the C_1-C_{12} HC speciation profiles showed that the percentage of total aromatics emissions for F-T and 100% biodiesel was also about one third and one half, respectively, of the percentage of aromatics emissions for RFD. However, the relative emissions of benzene by the 1990 Dodge were much higher for the 100% biodiesel and the F-T than for the RFD. The 1990 Dodge also emitted a percentage of alkenes on biodiesel that was twice as high as when burning other fuels. It should be noted that the overall HC speciation recoveries were lower than expected. The percentage of FID hydrocarbons accounted for by C_1-C_{12} GC bag species ranged from 25 to 45%. The C_8-C_{20} HC species accounted for only a small fraction of the total HC mass, i.e., less than 2%. Additional experiments will be conducted as part of future projects to examine sources of loss for hydrocarbon species.

Chemical analyses showed elemental and organic carbon to be the primary constituents of the diesel particulate, accounting for an average of 73 to 80% of the total mass for the four vehicles. Biodiesel had the highest organic carbon fractions for each of the test vehicles. Inorganic species including ions and elements represented a smaller portion of the composite total, ranging from 0.7 to 1.6% of the total particulate. All inorganic species had emission rates of the less than 1 mg/mi for each test vehicle. The only species with average emission rates of greater than 0.1 mg/mi for each of the test vehicles were SO_4^{2-}, NH_4^+, Si, S, Ca, and Zn. There was a trend of higher sulfate and sulfur emissions for the RFD and 80/20 blend fuels, consistent with the higher fuel sulfur levels in the RFD compared with the F-T and neat biodiesel. Total semi-volatile PAH emissions were relatively low and comparable for all of the test fuels. The contribution of particulate PAHs was near the background level for nearly all components despite the relatively substantial overall particulate levels. The overall low levels of PAHs can probably be attributed to the low levels of PAHs in all four test fuels.

These results somewhat contrast the results of previous studies which have shown more significant emissions reductions for alternative blends, especially for PM. Several factors may contribute to this discrepancy including differences in fuel properties. The F-T diesel used in this work, for example, had an aromatics content considerably higher than that for F-T fuels used in other studies. The higher aromatic F-T diesel used in this study would likely provide less significant emissions reductions than would be expected for the F-T fuels used in previous studies. Regarding the biodiesel fuels, a number of the previous studies have been conducted using a Federal average diesel, with aromatic contents ranging from 30-40% by volume. This is considerably higher than the 10% level for the California RFD used in this study. Other studies of biodiesel blends have, however, shown reductions in emissions reductions in comparison with California RFD. It is also recommended that the additional research be conducted on a larger fleet to determine whether the results obtain in this study are representative of the fleet as a whole.

1.0 Introduction

1.1 Background

Over the past several years there has been considerable effort to develop reformulated and alternative diesel fuels in California and throughout the United States. One of the primary motives for this effort has been to reduce diesel emissions. Federal and California regulations required changes in diesel specifications beginning in October, 1993. At this time, aromatic content of fuels in California was limited to no more than 10% by volume, with waivers granted to refiners for alternative blends for which emissions equivalence to a 10% aromatic reference fuel could be shown. Another important objective in developing alternative diesel fuels is to promote independence from imported petroleum sources. In this regard, the Energy Policy Act of 1992 (EPACT) was enacted to stimulate the research, development, and accelerated introduction of alternative fuel technologies. Under EPACT, DOE has established several programs to develop and evaluate possible alternatives to conventional diesel blends.

Two fuels that have received considerable attention recently as potential alternative fuels for diesel engines are biodiesel and Fischer-Tropsch (F-T) diesel. These fuels offer the important advantage that they can be domestically produced and can be derived from renewable sources. Both fuels also have properties similar to those of traditional diesel such that they can be substituted for diesel fuel with little or no engine modification. Recently, several legislative measures have been passed promoting increased use of biodiesel fuels. Congress has passed legislation allowing federal and state fleet managers to meet the Energy Policy Act's alternative-fuel vehicle (AFV) acquisition requirements by using biodiesel added to conventional diesel at blends of 20% and higher. The Transport Equity Act for the 21st Century also provides funds for transit operators to purchase alternative-fuel buses, which would include biodiesels.

Given the possibility of increased use of biodiesel or F-T diesel, it is important to quantify any potential emissions benefits or liabilities of these fuels. To date, several studies have shown that biodiesel can provide emissions reductions relative to standard petroleum diesel. Much of this work has focused on comparisons with Federal diesel rather than California reformulated diesel (RFD). Engine studies performed by the Southwest Research Institute (SwRI) showed reductions in hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM) with both 100% biodiesel and 20% blends of biodiesel compared with Federal #2 diesel (Sharp, 1997, 1998a, 1998b). Those studies also found some increases in nitrogen oxides (NO_x) emissions. Studies performed by the U.S. Bureau of Mines also found reductions in total diesel particulate from a compression engine with a diesel oxidation catalyst using 100% biodiesel and a 30% biodiesel blend, although the volatile organic portion of the PM increased (McDonald et al., 1995). Graboski et al. (1996) conducted emissions studies on a Detroit Diesel Series engine using blends of a 30% aromatic diesel and methyl soy ester. For this study, the biodiesel blends produced considerable reductions compared with the diesel #2 for PM, THC, and CO, with slight increases in NO_x emissions. Smith et al. (1998) also found considerable reductions in PM with a slight increase in NO_x for emissions tests conducted using a Caterpillar 3406 engine.

Recently, several studies have also made emissions comparisons between both biodiesel and F-T diesel and California diesel. Recent work by researchers at West Virginia University (WVU) showed reductions in HC, CO, NO_x and PM for an F-T diesel in comparison with a California diesel (Clark et al., 1999). These tests were conducted on a 1994 7.3 liter Navistar diesel engine over the hot-start portion of the Federal Test Procedure (FTP). Comparison with other biodiesel data presented in this study also indicates that biodiesel blends can provide reductions in PM, THC and CO, but increases in NO_x, relative to the California diesel. Starr (1997) conducted research on a Detroit Diesel series 60 engine and found a 20% biodiesel blend with Federal #2 diesel to have slightly lower PM with higher NO_x emissions than a California low aromatic diesel fuel. The effects of retarding engine timing on PM and NO_x emissions were also investigated. Researchers at the National Renewable Energy Laboratory (NREL) and WVU compared emissions for F-T and California diesel on trucks equipped with Caterpillar engines (Norton et al., 1998). These chassis dynamometer tests showed reductions in THC, CO, NO_x, and PM emissions for the F-T diesel in comparison with the California diesel. Sasol’s Slurry Phase Distillate (SSPD) diesel and SSPD blends in a Detroit Diesel Series 60 engine were tested over the hot-start portion of the FTP compared with California RFD (Schaberg et al., 1997). These results also indicated that the emissions of the California RFD could be matched with a blend of 40% F-T diesel and 60% 49-state diesel.

1.2 Objectives

The present program was designed to further investigate the effects of alternative diesel fuels on exhaust emission rates and reactivity in comparison with California RFD. In this project, California RFD was compared with biodiesel, an 80/20 (RFD/biodiesel) blend, and an F-T diesel fuel for emissions performance. Chassis dynamometer tests were performed on four vehicles using each of the four fuels. For these tests, emissions measurements were collected for regulated gaseous emissions and PM. Additional measurements were also performed to provide chemical characterization of the exhaust PM including elemental and organic carbon, ions and trace elements and metals, identification of semi-volatile and particulate phase polynuclear aromatic hydrocarbons (PAHs), and speciation of gas phase hydrocarbons and oxygenates. These measurements will provide valuable information for the development of particulate species profiles for source/receptor modeling and in assessing the reactivity, ozone-forming potential, and overall toxicity of the exhaust.

2.0 Experimental Procedures

2.1 Vehicle Recruitment

A total of four light heavy-duty diesel vehicles were recruited for vehicle testing. These vehicles were chosen from a randomly selected pool of in-use vehicles. The vehicles were chosen to represent major manufacturers of light heavy-duty diesels (Ford and Dodge) and two catalyst classes (non-catalyst and oxidation catalyst). Each vehicle was inspected to establish its general condition and ensure it was safe before being accepted for testing. The test vehicles and their characteristics are listed in Table 1.

Table 1. Vehicle Descriptions for Test Fleet

Model Year	Make	Model	Odometer (miles)	GVW (lbs.)	Engine Size (L)	Fuel, Air System	Catalyst
1996	Dodge	Ram 2500 PU	9838	8800	5.9	DFI, Turbo	OC
1995	Ford	F-350 PU	33217	9000	7.3	DFI, Turbo	OC
1990	Dodge	Ram 250 PU	115734	8510	5.9	DFI, Turbo	None
1988	Ford	F-250 PU	76469	8800	7.3	IDI, non-Turbo	None

DFI = Direct Fuel Injection, IDI = Indirect Fuel injection, OC = Oxidation Catalyst

2.2 Test Fuels

Each vehicle was tested on a series of four test fuels. The test fuels were:

- A 10% aromatic diesel representative of the baseline RFD in California. It was obtained from Phillips Chemical Co. in Borger, TX.
- A 100% biodiesel fuel, Envirodiesel, obtained from Taurus Lubricants Corporation in Lowell, MA.
- A blend of 80% RFD and 20% biodiesel, splash-blended by CE-CERT from the two fuels above.
- An F-T diesel obtained from Mossgas (PTY) Ltd. in Mossel Bay, South Africa.

Specifications for each of the test fuels are provided in Table 2.

Table 2. Selected Fuel Properties

	RFD	Biodiesel	80/20 Blend	Fischer-Tropsch
API gravity	38.7	28.2	36.0	45.2
Aromatics, wt %	9.5	NA	NA	10.1
PAHs, wt %	0.17	NA	NA	<0.1
Cetane index	49.0		NA	
Cetane number		53.0	NA	51.4
Distillation, T50, ºF	479	NA	510	
T90, ºF	550		641	610
Free glycerin, mass %	NA	0.006	NA	NA
Total glycerin, mass %	NA	0.147	NA	NA
Sulfur, ppm	330	40	280	<10

NA=Not Available

A number of the standard tests could not be performed on all fuels. Biodiesel is approximately a single boiling point compound and thus distillation tests are not applicable. The calculated Cetane index, which is based on diesel distillation properties, is also not applicable. Biodiesel also includes non-aromatic compounds that interfere with the standard method for measuring aromatics. Biodiesel is expected to have negligible levels of aromatics and PAHs, however. The glycerin test is applicable only to biodiesel.

2.3 Protocol for Vehicle Testing

All vehicles were tested over the FTP to obtain mass emission rates for total PM, THC, CO, and NO_x. THC measurements were collected using a heated sample line as specified in the Code of Federal Regulations (CFR) for diesel vehicles (§86.110-94). Vehicles were preconditioned prior to the first test on any new fuel by driving on the dynamometer over two back-to-back iterations of the LA4 driving schedule followed by an overnight soak at a temperature of approximately

72ºF. Each vehicle was tested at least twice on each of the four test fuels. In some cases additional tests were conducted to verify the observed emissions trends. All tests were conducted in CE-CERT's Vehicle Emission Research Laboratory (VERL) equipped with a Burke E. Porter 48-inch single-roll electric dynamometer and a 12-inch diameter tunnel for diesel vehicles.

To meet the program objectives regarding fuel effects on reactivity and toxicity, additional sampling was conducted for a subset of the FTP tests. Particle samples were collected for analysis of elemental and organic carbon, trace elements and metals, ions, PAHs, and particle size distribution. Gas-phase samples were collected for analysis of C_1-C_4, C_4-C_{12}, and C_8-C_{20} hydrocarbon species, C_1-C_8 carbonyls, and semi-volatile PAHs. Analysis of C_1-C_4 hydrocarbons, C_4-C_{12} hydrocarbons, C_1-C_8 carbonyls, and particle size distributions was done by CE-CERT. Analysis of C_8-C_{20} hydrocarbons, PAH, and particle composition was done by Desert Research Institute (DRI), Reno, NV. Table 3 shows the type of analyses conducted for each fuel/vehicle combination.

Table 3. Sample Collection and Analysis Matrix

		FTP 3-phase				Cumulative over 3 phases	
Vehicle	**Fuel**	**PM, gases**	**C_1-C_4, C_4-C_{12}**	**C_8-C_{20}**	**Carbonyl**	**Ions, XRF EC, OC**	**PAH**
96 Dodge	RFD	✓				✓	
96 Dodge	Fischer-T.	✓				✓	
96 Dodge	80/20 blend	✓				✓	
96 Dodge	100% BioD	✓				✓	
95 Ford	RFD	✓				✓	
95 Ford	Fischer-T.	✓				✓	
95 Ford	80/20 blend	✓				✓	
95 Ford	100% BioD	✓				✓	
90 Dodge	RFD	✓	✓		✓	✓	
90 Dodge	Fischer-T.	✓	✓		✓	✓	
90 Dodge	80/20 blend	✓	✓		✓	✓	
90 Dodge	100% BioD	✓	✓		✓	✓	
88 Ford	RFD	✓	✓	✓	✓	✓	✓
88 Ford	Fischer-T.	✓	✓	✓	✓	✓	✓
88 Ford	80/20 blend	✓	✓	✓	✓	✓	✓
88 Ford	100% BioD	✓	✓	✓	✓	✓	✓

2.4 Particulate Sample Collection

The sampling protocol for this project was designed to provide mass emissions rates, size distributions, and samples for analysis for organic and elemental carbon fractions of the particulate. The dilution tunnel used for sampling was fitted with three sampling probes located approximately 130 inches downstream of the exhaust mixing flange. The sampling configuration, filter media, and analyses to be performed are summarized below:

- Probe 1 was fitted with 47 mm, 2.0 µm Gelman Teflon membrane filters using a Pierburg particle sampling system to obtain total mass particulate emission rates for each phase of the FTP. Each filter assembly was fitted with a primary and a backup filter.

- Probe 2 was fitted with a two-way flow splitter. One filter holder was fitted with 47 mm Gelman Teflon membrane filters for analysis of trace elements and ions. A second filter holder was fitted with prefired Pallflex 2500 QAT-UP quartz fiber filters for organic and elemental carbon analyses, and detailed speciation of the particulate PAHs. Thin stainless steel rings were placed in front of the quartz fiber filters to provide a more uniform and well defined deposit for carbon analysis. For the 1988 Ford, the quartz filters were backed up using a vapor-phase trap for collection of PAHs consisting of XAD-4 resin (polystyrene, divinylbenzene polymer) sandwiched between two polyurethane foam plugs (PUF).

- Probe 3 was fitted with a MOUDI cascade impactor for collection of size segregated samples. For at least one test for each vehicle/fuel combination a complete MOUDI size distribution was obtained using the following cut-points: >18, 10, 5.6, 3.2, 1.8, 1.0, 0.56, 0.32, 0.18, 0.10, 0.056, and an after-filter for particles <0.056 µm. Additional MOUDI spectra were collected on a subset of the remaining tests using either a full or partial MOUDI configuration. The partial MOUDI was configured using only the inlet for particles greater than 18.0 µm, the 10 µm, 3.2 µm, 1.8 µm, and 1.0 µm impaction stages, and the after-filter to provide size distributions for PM_{10}, $PM_{2.5}$, and $PM_{1.0}$. Although there is no specific impaction substrate for the collection of 2.5 µm particulate, the mass of particulate below 2.5 µm can be obtained by assuming that half of the mass collected on the 1.8 µm impaction substrate is from sub-2.5 µm particles. Uncoated aluminum foils were used for impaction substrates together with 47 µm, 2.0 µm pore size Gelman Teflon membrane after-filters.

For each test, mass emission rates were determined for each phase of the FTP. Samples for chemical analysis on quartz-fiber filters and the PUF/XAD substrate, and Teflon membrane filters were collected cumulatively over the entire FTP. Chemical analyses were performed on samples from one test for each vehicle fuel combination. MOUDI samples were collected over only phase 2 of the FTP since the MOUDI has a tendency to become overloaded with high particulate emitting vehicles. All samples were collected at 20 liters per minute (lpm) with the exception of the MOUDI, which was operated at 30 lpm. All flows were measured and controlled using mass flow controllers, and all sampling is performed under isokinetic conditions using removable probe tips.

2.5 Particulate Sample Analysis

Teflon membrane filters and aluminum MOUDI substrates were weighted before and after sampling to determine the collected mass using an ATI Orion ultra-microbalance. The microbalance is located in an environmental weighing chamber maintained at a temperature of 25.3±0.6°C and a relative humidity of 44±6%. Before and at the completion of sample collection, substrates were preconditioned for at least 24 hours in the environmental chamber before weighing. Tunnel blanks were collected weekly throughout testing. Tunnel blanks were converted to mass emission rates based on sample flows and the length of the testing period. Particulate mass emission rates were corrected based on the average equivalent mass emission rates of 1.2±0.8 mg/mi.

The Teflon membrane filters collected from probe 2 were utilized for chemical analysis of metals and other trace elements, and sulfate, nitrate, and ammonium ions. All analyses were conducted by the Desert Research Institute (DRI). Samples were stored in petri dishes in a refrigerator prior to shipment to DRI. Shipment to DRI was in a cooler with blue ice packs. Metals and other trace elements were analyzed using x-ray fluorescence (XRF). Filters were extracted in a 60:40 mixture of isopropyl alcohol and distilled, deionized water for nitrate and sulfate analyses using ion chromatography. A separate extraction with distilled, deionized water was used for analysis of ammonium ions, since the isopropyl alcohol causes interference in the measurements of these two ions. Ammonium ions were measured using automated colorimetry.

The quartz fiber filters collected at probe 2 were used for elemental and organic carbon analyses. Quartz fiber filters were obtained from DRI after prefiring at 900°C for three hours to reduce background carbon levels. The filters were shipped in blue ice to CE-CERT and stored in a refrigerator until used. Following sample collection, filters were stored in a freezer in petri dishes lined with aluminum foil prior to return shipment to DRI in a cooler with blue ice packs. Elemental and organic carbon analyses were performed by DRI using the Thermal Optical Reflectance (TOR) method (Chow et al., 1993). Analyses were performed on a 0.512 cm^2 punch from the filter.

PAH analyses were performed on the PUF/XAD vapor-phase trap and quartz fiber filters. PUF/XAD backup cartridges were utilized to collect semi-volatile PAHs. XAD resin and PUF cartridges were obtained precleaned from DRI. The XAD resin was cleaned by washing with distilled water and methanol, followed by Soxhlet extraction for 48 hours with methanol. The XAD was then drained and Soxhlet extracted for an additional 48 hours with dichloromethane (CH_2Cl_2). The resin was dried in a vacuum oven at 50°C. A second Soxhlet extraction was then performed with dichloromethane for 48 hours. PUF cartridges were cleaned by first washing with distilled water, followed by Soxhlet extraction in acetone for 48 hours, followed by Soxhlet extraction for 48 hours in 10% diethyl ether in hexane. The extracted PUFs were then dried in a vacuum oven and dried at 50°C for approximately 3 days. XAD resin and PUF cartridges were stored in a freezer before and after sampling prior to return to DRI. XAD and PUF filters were shipped to CE-CERT from DRI, and from CE-CERT back to DRI in a cooler with blue ice.

The PUF/XAD vapor trap and the quartz fiber filter for each test were extracted separately for PAH analysis to allow separation of semi-volatile and particulate PAHs. The PUF plugs were Soxhlet extracted with 10% diethyl ether in hexane, while the filters and XAD resin were microwave extracted with dichloromethane. The PUF and XAD extracts were then combined into one semi-volatile extract. The semi-volatile extract, and the particulate extract from the quartz filter were then each reduced to a volume of ~1 ml by rotary evaporation and analyzed by GC/MS in selected ion monitoring mode.

2.6 Detailed Hydrocarbon Speciation Sampling and Analysis

Hydrocarbon speciation measurements were made for the 1990 Dodge Ram 250 and the 1988 Ford F250 to determine NMOG emission rates for at least one test on each fuel type. Hydrocarbon speciation measurements for C_1-C_{12} were conducted for both vehicles while Tenax hydrocarbon measurements for C_8-C_{20} were conducted on only the 1988 Ford F250. Samples for the C_1-C_{12} HC speciation were collected in 8L black Tedlar GC bags. Hydrocarbon speciation analyses for C_1-C_{12} were conducted utilizing the protocols developing during Auto/Oil Phase 2 (Siegl et al., 1993). Light hydrocarbons (C_1 through C_4) were measured using a Hewlett-Packard (HP) 5890 Series II GC with a flame ionization detector (FID) maintained at 250°C. A 15 m x 0.53 mm polyethylene glycol pre-column and a 50 m x 0.53 mm aluminum oxide “S” deactivation porous layer open tubular (PLOT) column were used. A 5-ml stainless steel sample loop was conditioned with the sample prior to analysis. A second HP 5890 Series II GC with a FID maintained at 300°C was used to measure the C_4 to C_{12} hydrocarbons. A 2 m x 0.32 mm deactivated fused silica pre-column and a 60 m x 0.32 mm HP-1 column was used. A 5-ml stainless steel sample loop was conditioned with the sample from the GC bag prior to analysis. Analyses were completed within four hours of sample collection.

Hydrocarbons in the range C_8-C_{20} were also collected for at least one test for each fuel type on the 1988 Ford F250. These higher hydrocarbons were collected using Tenax-TA solid adsorbent through a heated line (43°C) at flow rates of approximately 1 lpm. Prior to use, the Tenax-TA solid adsorbent was cleaned by DRI using a Soxhlet extraction with a hexane/acetone mixture, packed into Pyrex glass tubes and thermally conditioned for four hours by heating at 300°C under nitrogen purge. Approximately 10% of the precleaned Tenax cartridges were tested by GC/FID for purity prior to sampling. After sampling, the Tenax cartridges were capped tightly using clean Swagelok caps with graphite/vespel ferrules, placed in metal containers with activated charcoal on the bottom and refrigerated. Tenax cartridges were shipped to CE-CERT from DRI, and from CE-CERT back to DRI in a cooler with blue ice.

Tenax samples were analyzed by thermal desorption-cryogenic preconcentration method, followed by quantification by high resolution gas chromatography with flame ionization detection (GC/FID) of individual hydrocarbons. The Chrompack Thermal Desorption-Cold Trap

Injection (TCT) unit was used for sample desorption and cryogenic preconcentration. The desorption parameters were as follows: desorption temperature of 280°C, held for 8 min; trapping temperature –140°C, He flow 15 ml/min. A 30-cm piece of deactivated fused silica capillary tubing, packed with a small amount of glass wool, was used as a cold trap. After the cycle of desorption was completed, the cold trap was heated to 280°C within seconds and held for two minutes at this temperature. A 60 m DB-1 capillary column was used and the chromatographic conditions were as follows: initial column temperature of 30°C for two minutes, followed by programming at 6°C/min to a final temperature of 290°C and held isothermal for five minutes.

2.7 Carbonyl Analysis

Carbonyl measurements were made for the 1990 Dodge Ram 250 and the 1988 Ford F250 for at least one test on each fuel type. Dilute exhaust gas aldehydes and ketones were collected through a heated line onto dinitrophenyl-hydrazine (DNPH)-coated silica gel cartridges. The DNPH cartridges were analyzed by high performance liquid chromatography (HPLC).

3.0 Emissions Test Results

3.1 Mass Emission Results

The FTP weighted PM and gaseous mass emission rates for each vehicle/fuel combination are presented in Table 4 and Figures 1-4. These data represent the average of all tests conducted for each vehicle/fuel combination. The error bars in Figures 1-4 were calculated from the replicate tests for each vehicle/fuel combination as 2 times the standard deviation of the mean. The complete FTP data for each vehicle and fuel are presented in Appendix A.

The effect of fuel on PM emission rates varied significantly from vehicle to vehicle. PM emissions for the 1996 Dodge Ram were comparable for the different fuel types. For the 1995 Ford F350, the 100% biodiesel and 80/20 biodiesel blend produced higher emissions than RFD while the F-T diesel produced the lowest emissions. For the 1988 Ford F350, the biodiesel fuels and the F-T diesel all produced higher PM emissions compared with the RFD. The most dramatic effect on PM emissions on both an absolute and a relative scale were observed for the 1990 Dodge Ram. For this vehicle, PM emissions for all of the alternative fuels were significantly higher than those of the RFD, with dramatic increases observed for the 100% biodiesel and the 20% biodiesel blend. It should be noted that the 1990 Dodge was brought back and retested over the entire test sequence on the RFD, biodiesel and 20% biodiesel blend to verify the trends observed in the PM emissions. Similar results were observed over both testing periods and for replicate tests, indicating that the trends were very repeatable. It is not known how representative this vehicle is of the overall light heavy-duty vehicle fleet, however.

THC emissions were generally lower for the 100% biodiesel, the biodiesel blend, and the F-T diesel compared with the RFD, with the exception of the 20% biodiesel blend for the 1990 Dodge Ram. The 100% biodiesel fuel had the lowest THC emissions, with THC emissions considerably lower than those for the other fuels for all vehicles but the 1988 Ford F350. THC emissions for the 1988 Ford F350 were comparable for the different fuels.

Table 4. FTP Weighted Emissions Results for Diesel Vehicles on Different Fuel Blends

	1996 Dodge Ram 2500				1995 Ford F350				1990 Dodge Ram 250				1988 Ford F250			
	THC g/mi	CO g/mi	NO_x G/mi	Parts mg/mi	THC g/mi	CO g/mi	NO_x g/mi	Parts mg/mi	THC g/mi	CO g/mi	NO_x g/mi	Parts mg/mi	THC g/mi	CO g/mi	NO_x g/mi	Parts mg/mi
RFD	0.419	1.539	8.489	71.9	0.603	2.230	6.359	74.6	0.930	2.093	6.442	193.3	0.334	1.457	6.369	353.2
Bio-Diesel	0.254	1.433	8.304	64.4	0.201	1.720	6.450	106.7	0.738	2.269	7.012	828.1	0.314	1.282	7.054	434.1
80/20 Blend	0.331	1.418	8.315	59.3	0.480	1.895	6.126	98.7	1.111	2.194	6.303	467.9	0.305	1.378	6.393	401.1
Fisher-Tropsch	0.398	1.471	8.210	81.0	0.387	1.984	6.521	53.4	0.868	2.011	5.803	282.4	0.298	1.363	6.367	397.3

Figure 1. FTP Particulate Emissions

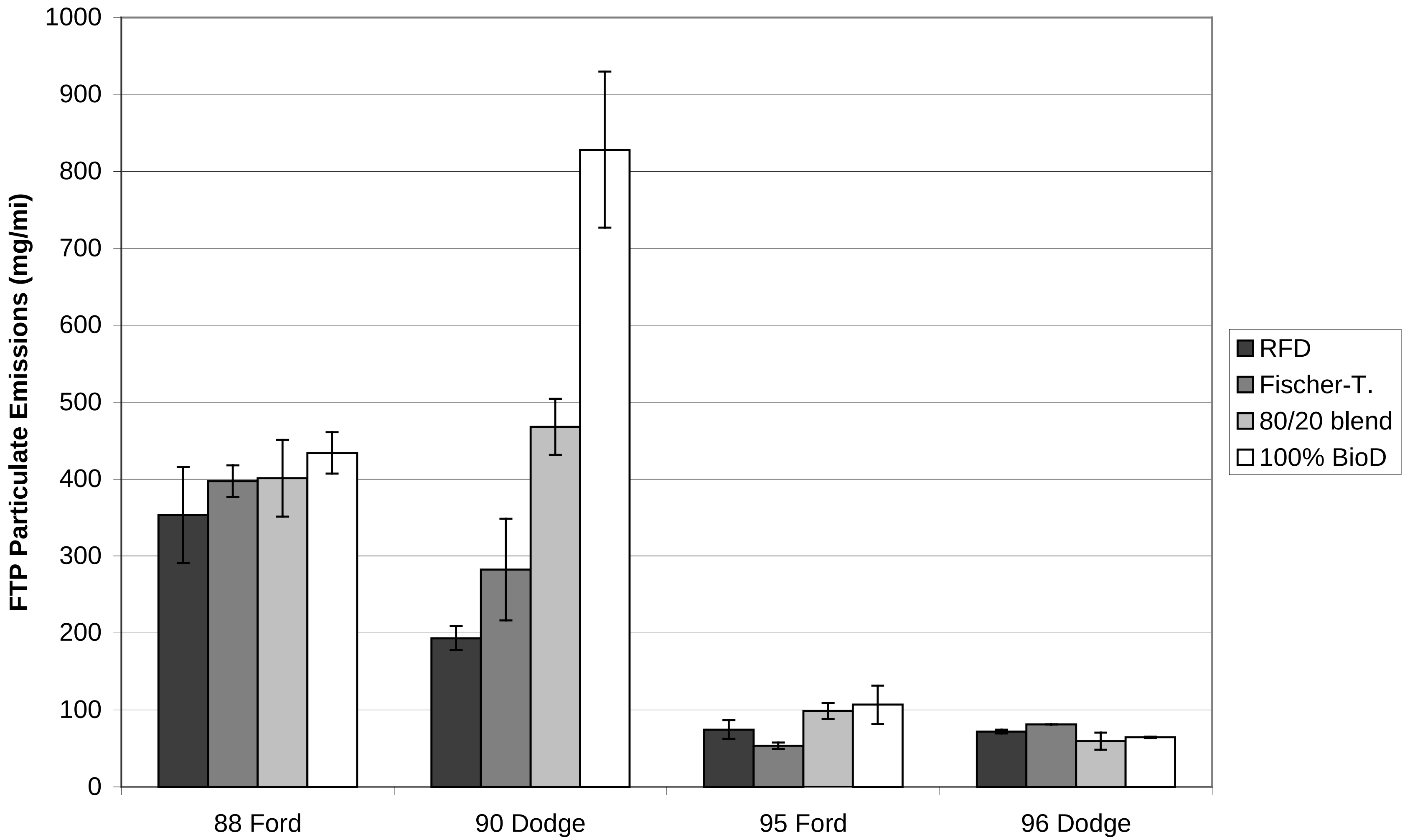


Figure 2. FTP Hydrocarbon Emissions

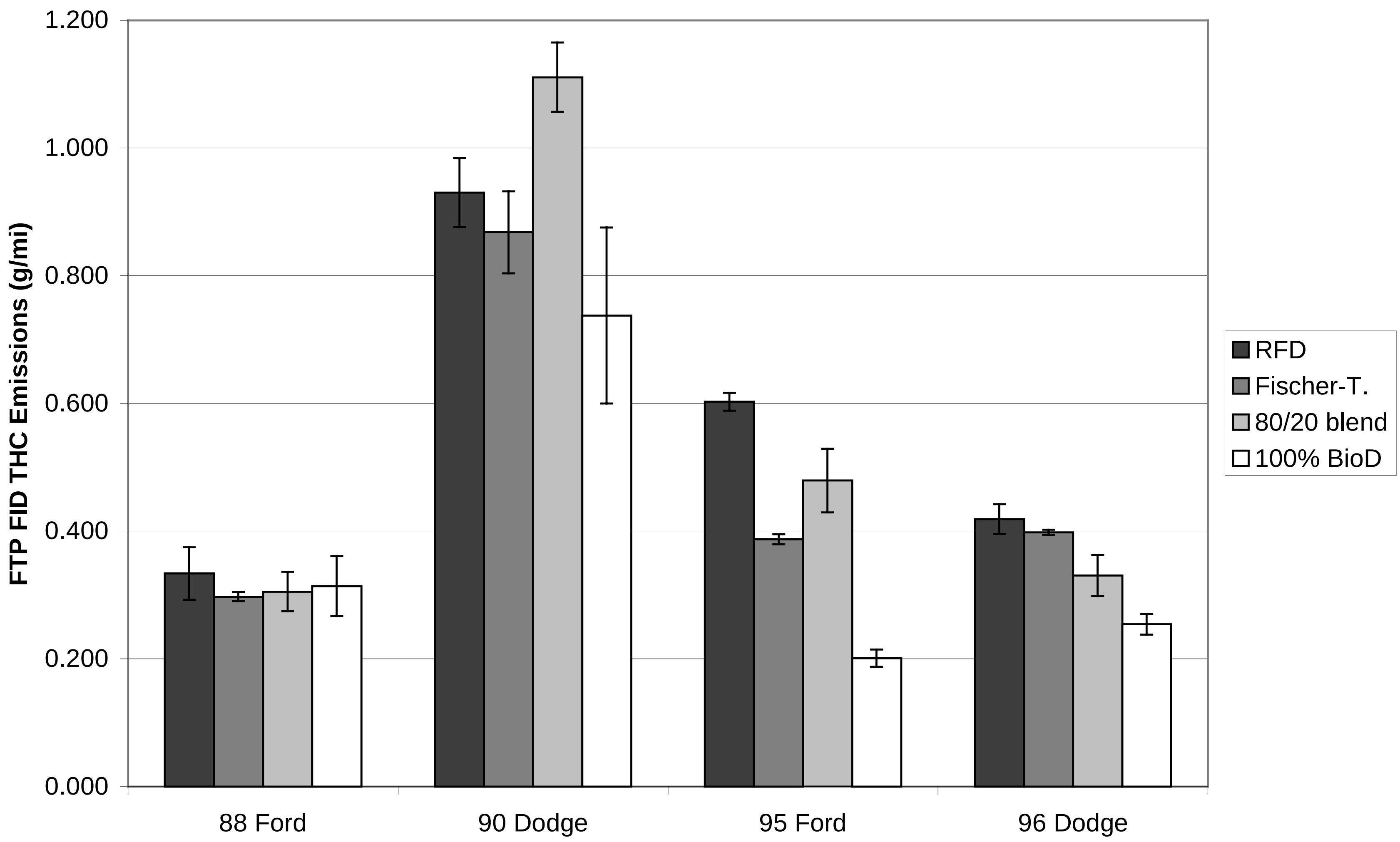


Figure 3. FTP CO Emissions

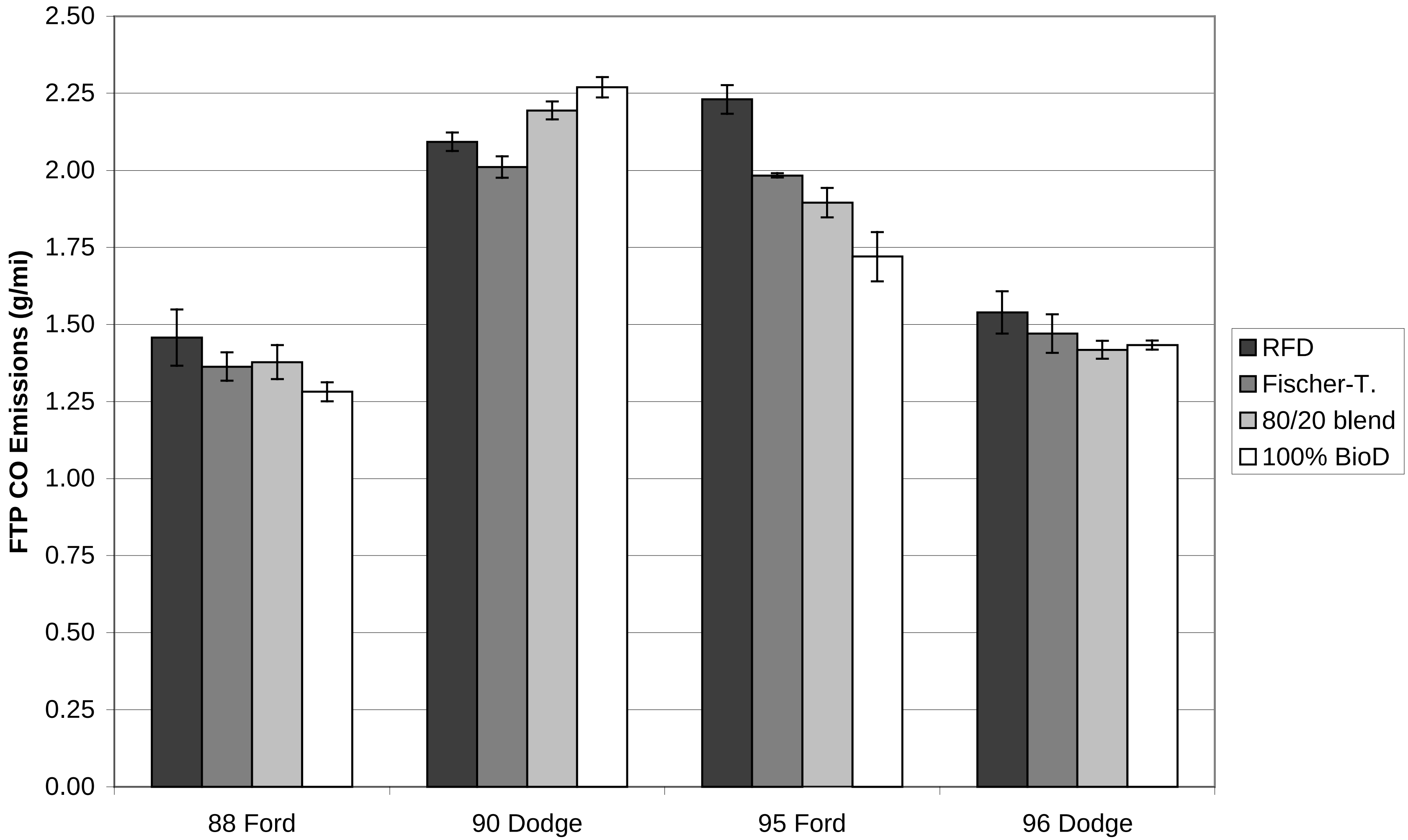
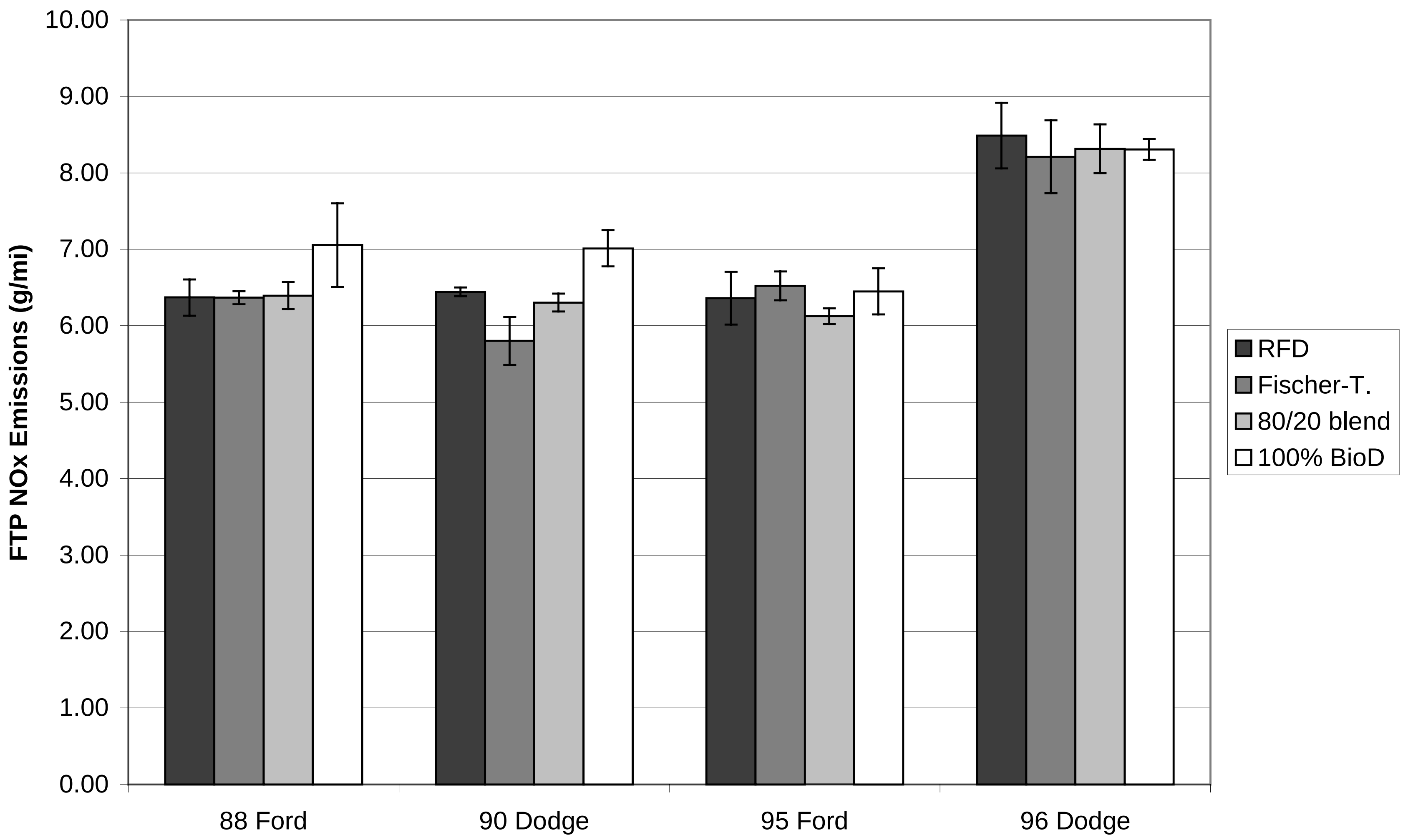


Figure 4. FTP NO_x Emissions



CO emissions were significantly lower for the all the alternative blends compared with RFD for the 1995 Ford F350. Lower CO emissions were also observed for the alternative fuels for the 1988 Ford F250 and the 1996 Dodge Ram, although these reductions were not as significant. For the 1990 Dodge Ram, CO emissions were slightly higher for the 1990 Dodge Ram on the biodiesel fuels and slightly lower on the F-T compared with RFD.

NO_x emissions for the alternative fuels and RFD were comparable for the two newest vehicles, the 1995 Ford and 1996 Dodge. Slightly higher NO_x emissions were found for the 1990 Dodge and 1988 Ford on 100% biodiesel, while NO_x emissions were slightly lower using the F-T diesel on the 1990 Dodge.

3.2 Hydrocarbon Speciation Results

Tables 5a and 5b summarize the results of C_1-C_{12} hydrocarbon species for compound classes and for a selection of potentially toxic compounds for the 1988 Ford and the 1990 Dodge. The detailed results for all measured C_1-C_{12} species are provided in Appendix B1. The 1988 Ford shows generally little difference among emissions for the different fuel types, except for benzene. The percentage emissions of benzene for the F-T and the 100% biodiesel fuels is about one third and one half, respectively, of the percentage emitted by RFD. For the 1990 Dodge, the percentage emissions of total aromatics for the F-T and the 100% biodiesel are also about one third and one half respectively of the percentage emitted by RFD. However, the relative emissions of benzene by the 1990 Dodge were much higher for the 100% biodiesel and the F-T than for the RFD. The 1990 Dodge also emits a percentage of alkenes on biodiesel that is twice as high as when burning the other fuels. While the results among replicates and among phases within a test are consistent, more vehicles are needed to determine whether these are fuel effects or vehicle effects.

Table 5a. Summary of C_1-C_{12} HC emission for compound classes

	90 Dodge RFD	90 Dodge Fischer-T	90 Dodge 80/20	90 Dodge 100% Bio	88 Ford RFD	88 Ford Fischer-T	88 Ford 80/20	88 Ford 100% Bio
HC by HFID (mg/mi)								
THC	1000	900	1190	805	352	295	304	343
HC by GC (mg/mi)								
Methane	18	17	20	7	2	1	3	1
NM Alkanes	17	16	15	18	12	7	10	17
Alkenes	91	105	113	153	77	89	84	94
Alkynes	15	17	19	22	9	9	10	8
Aromatics	73	22	90	32	15	9	12	15
Ethers	0	1	0	0	0	0	0	0
Unknowns	70	89	73	40	26	22	16	27
Total NMHC	267	250	310	265	139	135	134	162
HC by GC (% of FID NMHC)								
NM Alkanes	1.7%	1.8%	1.2%	2.2%	3.4%	2.4%	3.5%	4.8%
Alkenes	9.1%	11.8%	9.6%	19.0%	21.8%	30.0%	27.8%	26.7%
Alkynes	1.5%	1.9%	1.6%	2.8%	2.4%	2.9%	3.5%	2.3%
Aromatics	7.3%	2.5%	7.6%	3.9%	4.1%	2.9%	4.0%	4.3%
Ethers	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Unknowns	7.1%	10.0%	6.2%	5.0%	7.4%	7.3%	5.4%	7.6%
Total NMHC	26.8%	28.2%	26.3%	32.9%	39.2%	45.5%	44.2%	45.7%

Table 5b. Summary of C_1-C_{12} HC emissions for selected compounds

	90 Dodge RFD	90 Dodge Fischer-T	90 Dodge 80/20	90 Dodge 100% Bio	88 Ford RFD	88 Ford Fischer-T	88 Ford 80/20	88 Ford 100% Bio
Selected HC by GC (mg/mi)								
1,3-Butadiene	3.85	3.78	5.29	8.42	4.48	4.97	4.58	5.64
Benzene	1.57	4.99	4.19	13.42	3.99	1.31	2.72	2.48
Toluene	3.01	1.76	3.52	2.30	1.81	1.58	1.78	2.17
Ethylbenzene	0.47	0.54	0.69	0.49	0.35	0.19	0.10	0.25
o-Xylene	0.76	0.13	0.89	0.02	0.30	0.00	0.16	0.27
m&p-Xylene	0.22	0.17	0.48	0.36	0.17	0.29	0.25	0.68
n-Propylbenzene	0.96	0.00	1.16	0.30	0.04	0.00	0.03	0.05
i-Propylbenzene	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Styrene	1.30	0.89	1.72	2.33	0.84	0.18	0.45	0.83
Naphthalene	1.00	1.19	1.22	0.28	0.19	0.00	0.00	0.41
Select HC by GC (% of GC NMHC)								
1,3-Butadiene	1.4%	1.5%	1.7%	3.2%	3.2%	3.7%	3.4%	3.5%
Benzene	0.6%	2.0%	1.4%	5.1%	2.9%	1.0%	2.0%	1.5%
Toluene	1.1%	0.7%	1.1%	0.9%	1.3%	1.2%	1.3%	1.3%
Ethylbenzene	0.2%	0.2%	0.2%	0.2%	0.3%	0.1%	0.1%	0.2%
o-Xylene	0.3%	0.1%	0.3%	0.0%	0.2%	0.0%	0.1%	0.2%
m&p-Xylene	0.1%	0.1%	0.2%	0.1%	0.1%	0.2%	0.2%	0.4%
n-Propylbenzene	0.4%	0.0%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%
i-Propylbenzene	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Styrene	0.5%	0.4%	0.6%	0.9%	0.6%	0.1%	0.3%	0.5%
Naphthalene	0.4%	0.5%	0.4%	0.1%	0.1%	0.0%	0.0%	0.3%

Since diesel hydrocarbon (HC) emissions contain a number of compounds which extend beyond C_{12}, it is expected that the C_1-C_{12} species would represent only a portion of the HCs measured by the heated flame ionization detector (HFID) (Hammerle, et al, 1995). As shown in Tables 5a and 5b, the percentage of HFID HCs accounted for by the C_1-C_{12} species ranges from about 25 to 45%. The C_8-C_{20} Tenax HC results were expected to account for some of the discrepancy between the total FID HCs and the C_1-C_{12} species data. The total C_8-C_{20} HC results for the 1988 Ford, however, account for less than 2% of the THC by FID, as shown in Appendix B2. Additional experiments will be conducted as part of future programs to examine potential sources of loss for hydrocarbon species. One issue that will be further investigated is the collection temperatures for the Tenax samples. In particular, the heated line to the Tenax sampler was maintained at about 43°C for these experiments, or about 10°C less than the maximum temperature for particle sampling, while the heated line to the HFID was maintained at approximately 190°C, as specified in the CFR for diesel hydrocarbon sampling. The higher temperature of the HFID may cause it to respond to semi-volatile compounds that would be measured as particle mass on the FTP particulate filters.

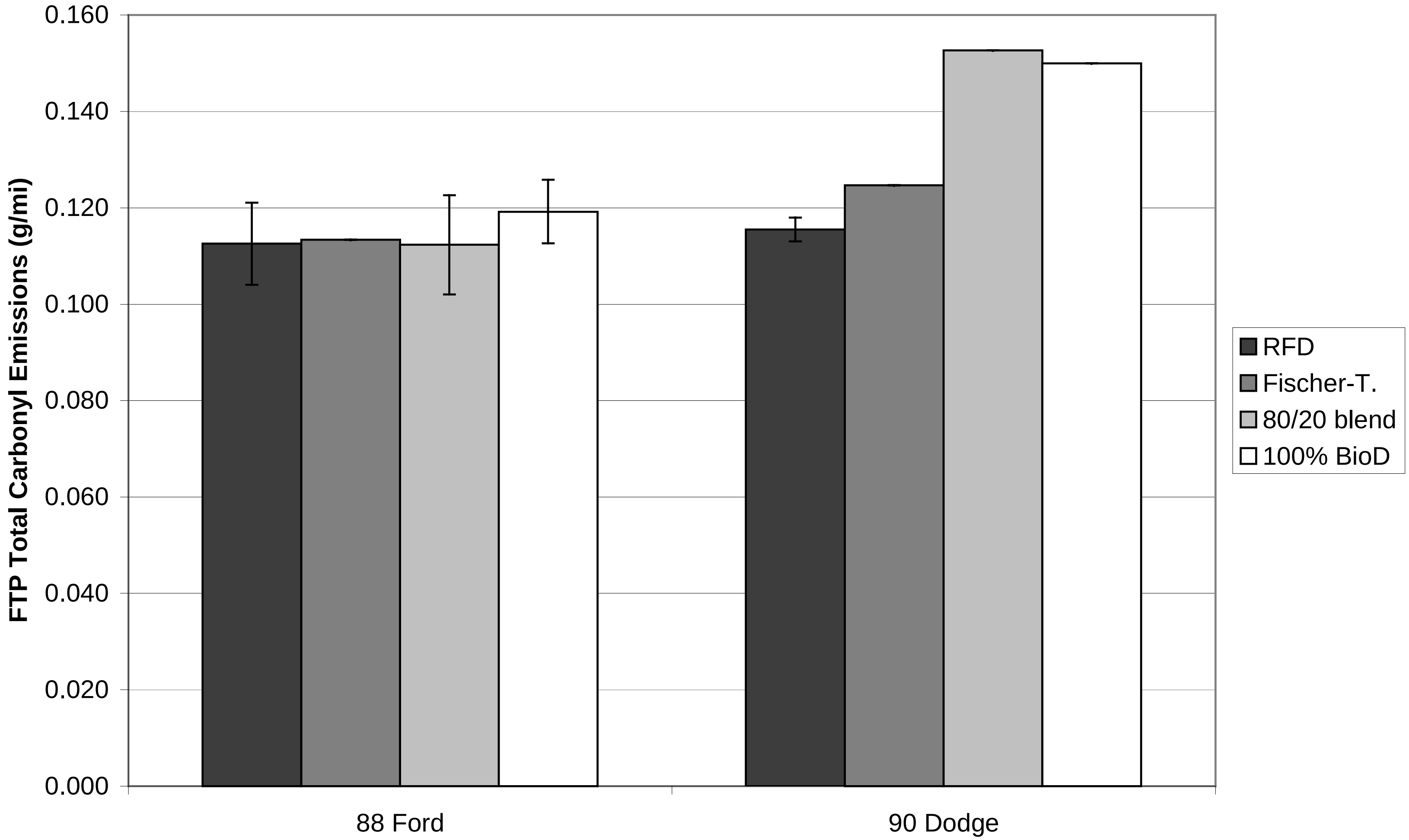
3.3 Carbonyl Emission Results

FTP weighted emission rates for total carbonyls in g/mile are shown in Table 6 and Figure 5 for the 1988 Ford and the 1990 Dodge. Table 6 also shows the percentage contributions of the carbonyl species. Fuel type does not influence carbonyl emissions for the 1988 Ford. For the 1990 Dodge, the alternative fuels show increased emissions of about 0.01 to 0.04 g/mi compared with California RFD. The carbonyl species composition profiles are similar among all fuel/vehicle combinations tested. The trend of increased emissions from alternative fuels for the 1990 Dodge but not the 1988 Ford is similar to the trend observed for PM emissions. A similar trend is not observed for THC emissions, however. Data in g/mi for all species measured are shown in Appendix B3.

Table 6. Summary of Carbonyl Emission Rates

Vehicle Fuel		90 Dodge RFD	90 Dodge Fischer-T	90 Dodge 80/20	90 Dodge 100% Bio	88 Ford RFD	88 Ford Fischer-T	88 Ford 80/20	88 Ford 100% Bio
Total Carbonyl	g/mi	0.114	0.125	0.153	0.151	0.113	0.113	0.112	0.119
Formaldehyde	%	55%	48%	45%	53%	50%	53%	51%	54%
Acetaldehyde	%	22%	23%	27%	20%	21%	23%	22%	22%
Acrolein	%	10%	8%	11%	4%	7%	9%	8%	6%
Propionaldehyde	%	4%	4%	5%	4%	4%	4%	4%	4%
Hexanaldehyde	%	1%	3%	0%	6%	3%	3%	4%	3%
Benzaldehyde	%	2%	3%	4%	3%	4%	1%	3%	2%
Acetone	%	1%	1%	2%	2%	2%	2%	2%	3%
Pentanaldehyde	%	2%	1%	2%	3%	2%	1%	1%	1%
Methacrolein	%	2%	2%	2%	1%	1%	2%	1%	1%
Butanone	%	0%	2%	0%	1%	2%	2%	1%	2%
Crotonaldehyde	%	1%	1%	1%	2%	1%	1%	1%	1%
p-Tolualdehyde	%	0%	4%	0%	1%	2%	0%	1%	0%
n-Butyraldehyde	%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 5. FTP Carbonyl Emissions



3.4 Particulate Size Distributions

The percentage of particulate mass <10 µm, <2.5 µm, and <1.0 µm is presented in Table 7 for each vehicle/fuel combination. The results show that greater than 90% of the mass is below 1 µm in diameter for all vehicle/fuel combinations. These results are consistent with previous MOUDI results for the diesel vehicles (Norbeck et al., 1998a,b). Complete MOUDI size distributions are presented in Appendix C. The results presented in Table 7 and Appendix C show that the size distributions are similar for different vehicle/fuel combinations, although there is a trend for the 100% biodiesel to have a larger mass fraction on the after-filter (aerodynamic diameter <0.056 µm). The 1988 Ford F350 also had a larger mass fraction on the after-filter than the other vehicles.

Table 7 Particle Mass Size Distribution

			Size Cut	
Vehicle	**Fuel**	**<10.0 µm**	**<2.5 µm**	**<1.0 µm**
1996 Dodge Ram	RFD	98.0%	95.4%	92.3%
	Fischer-T	98.4%	97.2%	94.8%
	80/20	95.6%	94.7%	90.0%
	B100	98.9%	98.6%	97.8%
Average		97.7%	96.5%	93.7%
1995 Ford F350	RFD	98.7%	96.3%	93.6%
	Fischer-T	100.0%	97.3%	94.5%
	80/20	99.1%	97.8%	96.3%
	B100	99.3%	98.0%	94.8%
Average		99.3%	97.3%	94.8%
1990 Dodge 250	RFD	99.5%	98.4%	96.1%
	Fischer-T	99.5%	98.7%	97.0%
	80/20	99.6%	99.5%	98.9%
	B100	99.8%	99.5%	98.4%
Average		99.6%	99.0%	97.6%
1988 Ford 250	RFD	99.5%	99.0%	98.0%
	Fischer-T	99.5%	99.1%	98.1%
	80/20	99.5%	99.3%	98.6%
	B100	96.1%	95.8%	94.8%
Average		98.7%	98.3%	97.4%

4.0 Particulate Chemical Analysis Results

4.1 Particulate Chemical Species

Chemical analyses were performed on one test for each vehicle/fuel combination to determine emissions for elemental and organic carbon, ions, and trace elements. The mass emissions results for each of the tests in presented in Table 8. The mass emission rates for individual chemical species are corrected for the contribution of trace components found in tunnel blanks and, as a result, include some negative values. The full results including measurement uncertainties are presented in Appendix D. The measurement errors are calculated by propagating the uncertainty for the chemical analysis and sampling volumes. Chemical components whose concentrations are at least twice the analytical uncertainty are shown in bold.

Table 9 gives the fractions of total carbon, inorganic compounds, and PAH as percentage of total particulate mass, and gives elemental carbon and organic carbon as a percentage of total carbon. The results show that elemental and organic carbon are the primary constituents for diesel particulate, consistent with the observations of other researchers (Hildemann et al., 1991, Watson et al., 1994, Cadle et al., 1998, Whitney, 1998). Total carbon accounted for an average of 73.3% to 79.9% of the total mass for the four vehicles. The elemental and organic fractions varied from vehicle to vehicle and for the different fuel types. Biodiesel had the highest fraction of organic carbon for each of the test vehicles. The 80/20 blend had the next-highest organic fraction for two of the four test vehicles, but this trend was not consistent over the other two test vehicles. The 1988 Ford F350 had the highest organic fractions for each of the test fuels, with significant differences between other vehicles for the RFD, Fischer-Tropsch, and 80/20 blend. Overall, the organic carbon fractions for the non-catalyst-equipped vehicles (1988 Ford and 1990 Dodge) were higher than those of the catalyst vehicles (1996 Dodge and 1995 Ford). The differences between the 1990 non-catalyst and 1995 catalyst vehicle were not significant, however.

Inorganic species including ions and elements represented a smaller portion of the composite total, ranging from 0.7 to 1.6% of the total particulate. All inorganic species had emission rates of less than 1 mg/mi for each test vehicle, with the only species with average emission rates of

Table 8. PM Emission Rates for Chemical Species (mg/mi)

Vehicle Fuel	96 Dodge RFD	96 Dodge Fischer-T.	96 Dodge 80/20	96 Dodge 100% Bio	95 Ford RFD	95 Ford Fischer-T.	95 Ford 80/20	95 Ford 100% Bio
FTP PM	**74.0**	**79.7**	**52.6**	**63.6**	**76.9**	**50.0**	**107.8**	**106.3**
OC	**28.0**	**38.7**	**22.0**	**32.0**	**39.5**	**26.5**	**56.8**	**64.6**
EC	**29.0**	**31.8**	**23.3**	**18.6**	**24.2**	**24.2**	**26.6**	**18.5**
TC	**56.9**	**70.5**	**45.3**	**50.5**	**63.7**	**50.6**	**83.4**	**83.1**
NO_3	0.00	0.00	**0.15**	**0.14**	0.00	**0.27**	0.08	0.00
SO_4	**0.41**	**0.22**	**0.38**	**0.42**	**0.45**	**0.17**	**0.53**	**0.28**
NH_4	**0.13**	0.09	0.08	**0.11**	**0.13**	0.06	**0.14**	**0.10**
Na	-0.06	0.00	-0.06	-0.01	-0.06	-0.06	-0.06	-0.06
Mg	0.00	-0.01	-0.02	-0.03	0.00	0.00	**0.03**	**0.04**
Al	**0.03**	0.01	**0.03**	0.00	0.01	0.01	-0.01	0.00
Si	**0.28**	**0.10**	**0.22**	**0.20**	**0.17**	**0.10**	**0.16**	**0.09**
P	**0.03**	**0.02**	**0.04**	**0.07**	**0.05**	**0.03**	**0.04**	**0.15**
S	**0.30**	**0.18**	**0.23**	**0.25**	**0.27**	**0.10**	**0.26**	**0.14**
Cl	**0.03**	**0.02**	**0.09**	**0.12**	**0.04**	**0.02**	**0.06**	**0.08**
K	0.00	0.00	0.01	**0.04**	0.01	-0.01	0.00	**0.02**
Ca	**0.16**	**0.12**	**0.11**	**0.14**	**0.14**	**0.07**	**0.14**	**0.15**
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe	**0.02**	**0.05**	**0.02**	**0.04**	**0.01**	**0.01**	**0.02**	**0.05**
Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu	0.00	0.00	**0.01**	**0.01**	0.00	0.00	**0.01**	**0.02**
Zn	**0.12**	**0.10**	**0.20**	**0.33**	**0.12**	**0.07**	**0.16**	**0.43**
Ga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Br	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
In	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
Sn	0.00	0.01	0.01	0.00	0.02	0.00	0.01	0.00
Sb	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00
Ba	-0.05	-0.06	-0.06	-0.06	0.01	0.01	0.00	-0.04
La	0.00	-0.07	-0.07	-0.07	-0.03	-0.06	-0.07	-0.01
Au	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	**0.01**	0.00	0.00	**0.01**	0.01	0.00	**0.02**	**0.11**
U	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. PM Emission Rates for Chemical Species (mg/mi) (CONTINUED)

Vehicle Fuel	90 Dodge RFD	90 Dodge Fischer-T.	90 Dodge 80/20	90 Dodge 100% Bio	88 Ford RFD	88 Ford Fischer-T.	88 Ford 80/20	88 Ford 100% Bio
FTP PM	**180.9**	**314.2**	**455.7**	**872.0**	**396.8**	**385.8**	**464.3**	**451.2**
OC	**93.0**	**147.5**	**268.0**	**436.9**	**296.2**	**291.1**	**320.1**	**363.1**
EC	**84.1**	**112.6**	**103.8**	**56.6**	**52.9**	**44.1**	**54.7**	**34.9**
TC	**177.1**	**260.2**	**371.8**	**493.5**	**349.1**	**335.3**	**374.8**	**398.0**
NO_3	**0.42**	**0.17**	**0.26**	0.00	**0.16**	**0.43**	**0.16**	**0.69**
SO_4	**1.18**	**0.20**	**1.43**	0.03	**0.85**	**0.14**	**0.85**	**0.39**
NH_4	**0.54**	**0.14**	**0.63**	**0.22**	**0.50**	**0.25**	**0.45**	**0.24**
Na	**0.16**	-0.01	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
Mg	0.03	-0.01	-0.04	-0.04	-0.04	-0.05	-0.01	0.01
Al	**0.05**	0.00	0.01	0.00	0.00	-0.01	0.01	0.03
Si	**0.44**	**0.30**	**0.35**	**0.31**	**0.17**	**0.14**	**0.18**	**0.12**
P	**0.05**	**0.03**	**0.05**	**0.10**	**0.37**	**0.29**	**0.40**	**0.50**
S	**0.75**	**0.23**	**0.83**	**0.54**	**1.27**	**0.54**	**1.26**	**0.73**
Cl	0.03	**0.02**	**0.05**	**0.17**	**0.08**	**0.09**	**0.05**	**0.12**
K	0.00	0.00	0.00	**0.06**	-0.01	-0.01	0.01	**0.18**
Ca	**0.13**	**0.09**	**0.11**	**0.15**	**0.96**	**0.74**	**0.90**	**1.04**
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Fe	**0.01**	**0.02**	**0.03**	**0.10**	**0.05**	**0.04**	**0.06**	**0.27**
Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu	0.00	0.00	**0.00**	**0.01**	**0.01**	0.00	**0.01**	**0.02**
Zn	**0.09**	**0.08**	**0.15**	**0.32**	**0.84**	**0.61**	**0.80**	**1.08**
Ga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Br	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
Rb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr	0.00	0.00	0.00	0.00	**0.01**	0.00	**0.00**	**0.01**
Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
In	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Sn	0.00	0.02	0.01	0.01	0.02	0.00	0.01	0.00
Sb	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Ba	-0.06	-0.06	0.02	0.01	0.03	0.01	-0.06	-0.05
La	0.08	-0.07	-0.05	0.05	-0.05	-0.04	-0.04	-0.04
Au	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	0.00	0.00	0.00	**0.02**	**0.02**	0.00	0.01	**0.04**
U	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 9 Particle Mass Fractions

Vehicle	Fuel	FTP PM mg/mi	OC % of TC	EC % of TC	TC % of PM	Elements +Ions % of PM	Total PAH % of PM
96 Dodge	RFD	74.0	49.1%	50.9%	67.7%	1.5%	
96 Dodge	Fischer-T.	79.7	54.9%	45.1%	87.1%	0.9%	
96 Dodge	80/20	52.6	48.5%	51.5%	73.0%	2.0%	
96 Dodge	100% Bio	63.6	63.3%	36.8%	65.7%	2.1%	
	Average	**67.5**	**54.0%**	**46.1%**	**73.4%**	**1.6%**	
95 Ford	RFD	76.9	62.0%	38.0%	73.4%	1.4%	
95 Ford	Fischer-T.	50.0	52.2%	47.8%	85.0%	1.2%	
95 Ford	80/20	107.8	68.1%	31.9%	74.0%	1.2%	
95 Ford	100% Bio	106.3	77.7%	22.3%	76.4%	1.3%	
	Average	**85.3**	**65.0%**	**35.0%**	**77.2%**	**1.3%**	
90 Dodge	RFD	180.9	52.5%	47.5%	78.5%	1.6%	
90 Dodge	Fischer-T.	314.2	56.7%	43.3%	87.4%	0.4%	
90 Dodge	80/20	455.7	72.1%	27.9%	78.4%	0.7%	
90 Dodge	100% Bio	872.0	88.5%	11.5%	49.0%	0.2%	
	Average	**455.7**	**67.5%**	**32.6%**	**73.3%**	**0.7%**	
88 Ford	RFD	396.8	84.8%	15.2%	75.1%	1.1%	0.3%
88 Ford	Fischer-T.	385.8	86.8%	13.2%	86.5%	0.8%	0.3%
88 Ford	80/20	464.3	85.4%	14.6%	80.7%	1.0%	0.2%
88 Ford	100% Bio	451.2	91.2%	8.8%	77.2%	1.0%	0.3%
	Average	**424.5**	**87.1%**	**13.0%**	**79.9%**	**1.0%**	**0.3%**

greater than 0.1 mg/mi for each of the test vehicles being SO_4^{2-}, NH_4^+, Si, S, Ca, and Zn. The most significant vehicle differences are the higher ion and element emissions for the 1990 Dodge Ram and the 1988 Ford F-250, consistent with their higher overall PM emission rates. Regarding fuel differences, there is a trend of higher sulfate and sulfur emissions for the RFD and 80/20 blend fuels. This is consistent with the higher fuel sulfur levels in the RFD compared with the F-T and neat biodiesel. The RFD and 80/20 blend also have higher ammonium emissions than the F-T and neat biodiesel for the two non-catalyst vehicles. The neat biodiesel is the only fuel that emits K, which it emits from all four vehicles. K is frequently used as a tracer for vegetative burning, which is consistent with the vegetative source of the biodiesel. The neat biodiesel also generally has higher emissions of Zn, Fe, Cl, P, and Pb, than the other fuels across all four vehicles, though the trends are not always strong.

4.2 PAH Emission Results

PAH emissions were collected for the 1988 Ford F250 for each fuel type. These results are presented in Table 10 for the semi-volatile PAHs and in Table 11 for the particulate PAHs. These tables include the total mass emissions rates of semi-volatile and particulate PAHs and a listing of the individual species whose concentrations were at least twice the analytical uncertainty for at least one of the fuels. A pooled measurement uncertainty is also included. The pooled measurement uncertainty is calculated by propagating the uncertainty for the chemical analysis and sampling volumes over all tests. A listing of all semi-volatile and particulate species is provided in Appendix E.

Total semi-volatile PAH emissions were relatively low and comparable for all of the test fuels. Semi-volatile PAHs averaged 0.91 mg/mi for the four tests with a range from 0.82 to 1.02 mg/mi. This represents 0.2 to 0.3% of the total particulate mass. The distribution of PAHs consists primarily of naphthalene, 2-methylnaphthalene and 1-methylnaphthalene with the profile expected for semi-volatile PAHs from vehicles. Other PAHs present at levels greater than twice the standard deviations include biphenyl, 1-ethyl-2-methylnaphthalene, 3-, 2-, and 4-methylbiphenyl, F-trimethylnapthalene, 2,3,5-trimethylnapthalene, fluorene, phenanthrene, and 2-methylphenanthrene. The PAH distributions show only minor differences between different fuels, such as lower emissions of methylbiphenyls for the biodiesel compared to the other fuels. Additional samples and vehicles would be required to determine if these minor differences are characteristic of the fuel.

The contribution from the particulate PAHs was near background levels for nearly all components despite the relatively substantial overall particulate levels. Particle PAH totals ranged from 0.17 to 0.22 mg/mi for the different fuels. Among the particle PAHs, the single largest component was pyrene, at 0.03 mg/mi. The remaining measurable compounds consisted primarily of various methyl-, dimethyl-, and unsubstituted phenanthrenes. The overall low levels of both semi-volatile and particulate PAHs can probably be attributed to the low levels of PAHs in all four of the test fuels.

Table 10 Semi-volatile PAHs for 1988 Ford

Fuel	RFD mg/mi	F-T mg/mi	80/20 mg/mi	100% BioD mg/mi	Uncert mg/mi
FTP PM	396.8	385.8	464.3	451.2	
Organic Carbon	296.2	291.1	320.1	363.1	
Elemental Carbon	52.9	44.1	54.7	34.9	
Total Carbon	349.1	335.3	374.8	398.0	
Total Semi-volatile PAH	**0.816**	**1.017**	**0.975**	**0.831**	0.068
Naphthalene	**0.308**	**0.468**	**0.479**	**0.410**	0.041
2-Menaphthalene	**0.069**	**0.077**	**0.062**	**0.088**	0.014
1-Menaphthalene	**0.060**	**0.068**	**0.063**	**0.080**	0.011
Biphenyl	**0.021**	**0.023**	**0.028**	**0.022**	0.007
2-Ethyl-1-methylnaphthalene	**0.011**	**0.016**	**0.015**	**0.011**	0.005
1,7+1,3+1,6-Dimenaphthalene	0.032	**0.039**	**0.036**	0.027	0.017
2-Methylbiphenyl	**0.032**	**0.057**	**0.024**	0.003	0.007
3-Methylbiphenyl	**0.042**	**0.034**	**0.041**	0.009	0.007
4-Methylbiphenyl	**0.015**	**0.019**	**0.020**	**0.008**	0.003
A-Trimethylnaphthalene	**0.007**	**0.007**	**0.007**	**0.006**	0.003
B-Trimethylnaphthalene	**0.008**	**0.009**	**0.007**	**0.007**	0.002
C-Trimethylnaphthalene	**0.006**	**0.008**	0.004	**0.007**	0.002
E-Trimethylnaphthalene	**0.005**	**0.006**	0.004	**0.005**	0.002
F-Trimethylnaphthalene	**0.013**	**0.008**	**0.009**	**0.007**	0.002
2,3,5+I-Trimethylnapthalene	**0.010**	**0.008**	**0.007**	**0.006**	0.002
Acenaphthylene	**0.030**	**0.037**	0.027	**0.043**	0.014
Fluorene	**0.018**	**0.019**	**0.018**	**0.015**	0.007
Phenanthrene	**0.031**	**0.016**	**0.014**	**0.011**	0.004
A-Methylfluorene	**0.005**	**0.006**	0.004	0.002	0.002
1-Methylfluorene	0.006	0.002	**0.011**	0.003	0.004
A-Methylphenanthrene	**0.010**	0.005	**0.006**	0.005	0.003
2-Methylphenanthrene	**0.013**	**0.008**	**0.007**	**0.007**	0.002

Note: Concentrations that are at least twice the analytical uncertainty are shown in bold.
Total PAHs include compounds not listed.

Table 11. Particulate PAHs for 1988 Ford

Fuel	**RFD mg/mi**	**Fischer-T. mg/mi**	**80/20 Blend mg/mi**	**100% BioD mg/mi**	**Uncert mg/mi**
FTP PM	396.8	385.8	464.3	451.2	
Organic Carbon	296.2	291.1	320.1	363.1	
Elemental Carbon	52.9	44.1	54.7	34.9	
Total Carbon	349.1	335.3	374.8	398.0	
Total Particulate PAH	**0.193**	**0.166**	**0.204**	**0.219**	
Phenanthrene	**0.010**	**0.008**	**0.009**	**0.011**	0.002
A-Methylphenanthrene	**0.011**	**0.010**	**0.014**	**0.019**	0.003
2-Methylphenanthrene	**0.016**	**0.012**	**0.018**	**0.019**	0.002
C-Methylphenanthrene	**0.005**	0.004	**0.006**	**0.006**	0.003
1-Methylphenanthrene	**0.009**	0.004	**0.008**	**0.007**	0.002
A-Dimethylphenanthrene	**0.011**	**0.013**	**0.011**	**0.013**	0.003
B-Dimethylphenanthrene	**0.005**	**0.012**	**0.008**	**0.005**	0.003
C-Dimethylphenanthrene	0.016	0.000	**0.021**	**0.017**	0.008
1,7-Dimethylphenanthrene	**0.009**	**0.009**	**0.009**	**0.009**	0.004
D-Dimethylphenanthrene	**0.007**	**0.006**	**0.006**	**0.004**	0.002
E-Dimethylphenanthrene	**0.006**	**0.009**	**0.007**	**0.007**	0.003
Fluoranthene	0.006	0.009	0.011	**0.023**	0.006
Pyrene	**0.033**	0.014	**0.026**	**0.032**	0.008
C-Methylpyrene/methyfluoranthene	0.000	**0.007**	0.000	0.001	0.002
4-Methylpyrene	**0.007**	0.005	**0.010**	**0.007**	0.003
1-Methylpyrene	0.000	0.004	**0.008**	**0.005**	0.003

Note: Concentrations that are at least twice the analytical uncertainty are shown in bold.
Total PAHs include compounds not listed.

5.0 Discussion

These results somewhat contrast the results of previous studies, which have shown more significant emissions reductions for biodiesel and F-T blends, especially for PM. Several factors may contribute to this discrepancy, including differences in fuel properties. The F-T diesel used in this work, for example, had a 10% aromatic content, considerably higher than the aromatic levels of 2% or less for F-T fuels used in other studies (Clark et al., 1999; Norton et al., 1998; Schaberg et al., 1997). The higher aromatic F-T diesel used in this study would likely provide less significant emissions reductions than would be expected for the F-T fuels used in previous studies. Regarding the biodiesel fuels, a number of the previous studies have been conducted using a Federal average diesel, with aromatic contents ranging from 30-40%by volume (Sharp, 1997, 1998a, 1998b; McDonald et al., 1995; Graboski et al., 1996; Smith et al., 1998). This is considerably higher than 10% level for the California RFD used in this study. Other studies of biodiesel blends, however, have shown reductions in emissions reductions in comparison with California RFD (Clark et al., 1999; Starr, 1997). It also should be noted that most commercially available diesel fuels in California have higher levels of PAHs than the RFD used in this study. Thus, it is possible that larger differences in PAH emissions could be observed between an actual in-use California diesel fuel and biodiesel and F-T diesels.

It is also important to note that these results were obtained over a relatively small vehicle fleet that may not be representative of the overall vehicle population. For the 1990 Dodge, in particular, significant increases were observed in PM emission rates for the biodiesel fuels. While very repeatable over replicate tests and different test periods, this trend for the 1990 Dodge may indicate that this vehicle is not representative of the overall light heavy-duty vehicle fleet. Two of the four vehicles used in this study were also equipped with catalysts, which would tend to reduce the differences observed between different fuels for tailpipe emissions in comparison with engine out emissions.

6.0 Summary and Conclusions

The present program was designed to further investigate the effects of alternative diesel fuels on exhaust emission rates in comparison with California RFD. In this project, California RFD was compared with biodiesel, an 80/20 (RFD/biodiesel) blend, and a F-T diesel fuel for emissions performance. Chassis dynamometer tests were performed on four vehicles using each of the four fuels. The major results of this study are:

- For the biodiesel and biodiesel blend, particulate emission rates were slightly higher for two the test vehicles and significantly higher for a third test vehicle. While very repeatable over replicate tests and different test periods, the trend of significantly higher PM emissions on alternative fuels for one of the test vehicles may indicate that this vehicle is not representative of the overall light heavy-duty vehicle fleet. Particulate emissions for the F-T diesel were higher for two of the test vehicles and lower for one of the test vehicles.

- THC emissions were generally lower for the neat biodiesel, the biodiesel blend, and the F-T diesel compared with the RFD. The 100% biodiesel fuel had the lowest overall THC emissions, with THC emissions considerably lower than those for the other fuels for all vehicles but the 1988 Ford F350.

- CO emissions were significantly lower for the alternative fuels for the 1995 Ford, and slightly lower for the 1988 Ford and 1996 Dodge. Higher CO emissions were observed for the biodiesel and biodiesel blend over the 1990 Dodge.

- NO_x emissions for the alternative fuels and RFD were comparable for the two newest vehicles, the 1995 Ford and 1996 Dodge. Slightly higher NO_x emissions were found for the 1990 Dodge and 1988 Ford on 100% biodiesel, while the F-T fuel was slightly lower for the 1990 Dodge.

- HC speciation data were obtained for C_1-C_{12} for the 1988 Ford and the 1990 Dodge and C_8-C_{20} for the 1988 Ford. The C_1-C_{12} HC speciation profiles for the 1988 Ford showed little difference among emissions for the different fuel types, except for benzene. The emissions of benzene for the F-T and the 100% biodiesel fuels were about one third and one half, respectively, of the percentage emitted by RFD.

- For the 1990 Dodge, the C_1-C_{12} HC speciation profiles showed that the percentage of total aromatics emissions for F-T and 100% biodiesel was also about one third and one half, respectively, of the percentage of aromatics emissions for RFD. However, the relative emissions of benzene by the 1990 Dodge were much higher for the 100% biodiesel and the F-T compared to the RFD. The 1990 Dodge also emitted a percentage of alkenes on biodiesel that was twice as high as when burning other fuels.

- The overall HC speciation recoveries were lower than expected. The percentage of FID hydrocarbons accounted for by C_1-C_{12} GC bag species ranged from 25 to 45%. The C_8-C_{20} HC species accounted for only a small fraction of the total HC mass, i.e., less than 2%.

- Greater than 90% of the PM mass was below 1 μm in aerodynamic diameter for all vehicle/fuel combinations. The size distributions were similar for different vehicle/fuel combinations, although there was a trend for the 100% biodiesel to have a larger mass fraction on the after-filter (aerodynamic diameter <0.056 μm).

- Chemical analyses showed elemental and organic carbon to be the primary constituents of the diesel particulate, accounting for an average of 73 to 80% of the total mass for the four vehicles. Biodiesel had the highest organic carbon fractions for each of the test vehicles.

- Inorganic species including ions and elements represented a smaller portion of the composite total, ranging from 0.7 to 1.6% of the total particulate. All inorganic species had emission rates of the less than 1 mg/mi for each test vehicle, with the only species with average emission rates of greater than 0.1 mg/mi for each of the test vehicles being SO_4^{2-}, NH_4^+, Si, S, Ca, and Zn.

- There was a trend of higher sulfate and sulfur emissions for the RFD and 80/20 blend fuels, consistent with the higher fuel sulfur levels in the RFD compared with the F-T and 100% biodiesel. The 100% biodiesel was the only fuel that emitted K, consistent with the vegetative source of the biodiesel.

- Total semi-volatile PAH emissions were relatively low and comparable for all of the test fuels. The contribution of particulate PAHs was near the background level for nearly all components despite the relatively substantial overall particulate levels. The overall low levels of PAHs can probably be attributed to the low levels of PAHs in all four test fuels.

7.0 Recommendations

Based on the results of this study, the following recommendations are made:

- Comparisons should be made with California RFD blends with varying levels of aromatics to more adequately assess the impact of biodiesel, biodiesel blends, and Fischer-Tropsch fuels on exhaust emission rates and composition. California RFD blends with higher contents of PAHs should be investigated to determine the effect of fuel PAH levels on exhaust PAHs levels.

- Additional studies should be conducted with F-T fuels with lower aromatic content, more typical of the fuels used in previous studies.

- An expanded database of emissions on a larger, more representative fleet should be collected. In particular, it is important to determine if the large increases in particulates observed for the 1990 Dodge were an anomaly or if such increase in emissions would be found for a non-negligible portion of the overall vehicle fleet.

- The effects of longer term fuel conditioning should be further investigated.

- The testing program should be expanded to incorporate testing on heavy heavy-duty diesel vehicles.

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Appendix A. FTP Emissions Results

1996 Dodge Ram 2500 PU		Bag 1				Bag 2				Bag 3				Weighted			
		THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.
Test #	Fuel	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi
H9805028	RFD	0.455	2.252	7.069	80.5	0.477	1.489	9.514	70.9	0.322	1.010	6.520	61.0	0.430	1.515	8.188	70.2
H9805030	RFD	0.502	2.491	7.063	90.8	0.467	1.581	9.505	65.2	0.329	1.053	6.451	82.7	0.437	1.625	8.162	75.3
H9808048	RFD	0.430	2.148	7.413	80.5	0.422	1.510	10.13	69.4	0.307	0.956	6.972	67.2	0.391	1.490	8.704	71.1
H9808050	RFD	0.490	2.306	7.673	82.2	0.441	1.533	10.36	68.9	0.313	0.923	7.069	66.5	0.417	1.525	8.901	71.0
	RFD Ave.	0.469	2.299	7.305	83.5	0.452	1.528	9.878	68.6	0.318	0.986	6.753	69.4	0.419	1.539	8.489	71.9
H9805041	80/20 blend	0.344	1.977	7.060	71.4	0.334	1.423	9.400	49.0	0.244	0.923	6.498	49.7	0.311	1.400	8.119	53.8
H9805043	80/20 blend	0.404	2.019	7.163	82.6	0.373	1.464	9.889	63.4	0.265	0.941	6.920	54.3	0.35	1.435	8.511	64.9
	80/20 Ave.	0.374	1.998	7.112	77.0	0.354	1.444	9.645	56.2	0.255	0.932	6.709	52.0	0.331	1.418	8.315	59.3
H9805032	100% BioD	0.302	2.119	6.985	98.8	0.262	1.475	9.693	53.0	0.165	0.868	6.977	58.5	0.244	1.442	8.388	64.0
H9805035	100% BioD	0.319	2.022	6.920	93.8	0.286	1.455	9.545	53.9	0.180	0.916	6.692	63.8	0.264	1.424	8.220	64.9
	100% Ave.	0.311	2.071	6.953	96.3	0.274	1.465	9.619	53.4	0.173	0.892	6.835	61.1	0.254	1.433	8.304	64.4
H9808052	Fischer-T.	0.490	2.173	7.131	97.7	0.417	1.517	9.851	82.0	0.300	0.967	6.787	66.3	0.400	1.502	8.448	80.9
H9808054	Fischer-T.	0.461	2.031	6.757	109.5	0.421	1.471	9.283	76.7	0.302	0.932	6.408	67.5	0.396	1.439	7.971	81.0
	F-T Ave.	0.474	2.102	6.944	103.6	0.419	1.494	9.567	79.3	0.301	0.950	6.598	66.9	0.398	1.471	8.210	81.0

1995 Ford F350		Bag 1				Bag 2				Bag 3				Weighted			
		THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.
Test #	Fuel	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi
H9805051	RFD	0.433	2.541	7.305	52.2	0.730	2.421	6.085	58.7	0.521	1.392	4.817	84.3	0.611	2.163	5.990	64.4
H9805054	RFD	0.489	2.712	7.583	69.4	0.692	2.499	6.272	66.4	0.564	1.500	4.977	106.9	0.615	2.269	6.188	78.1
H9807070	RFD	0.472	2.461	8.127	52.6	0.642	2.530	6.887	58.7	0.558	1.565	5.575	88.4	0.584	2.251	6.783	65.6
H9807072	RFD	0.519	2.602	7.740	88.6	0.662	2.481	6.582	74.3	0.544	1.506	5.319	121.3	0.600	2.238	6.475	90.2
	RFD Ave.	0.478	2.579	7.689	65.7	0.682	2.483	6.457	64.5	0.547	1.491	5.172	100.2	0.603	2.23	6.359	74.6
H9806009	80/20 blend	0.379	2.290	7.208	65.8	0.488	2.050	6.123	86.3	0.374	1.190	4.894	132.9	0.434	1.864	6.011	94.8
H9806012	80/20 blend	0.360	2.283	7.543	84.4	0.488	2.017	6.196	95.7	0.410	1.188	5.015	152.7	0.440	1.845	6.15	109.0
H9807076	80/20 blend	0.454	2.295	7.610	63.7	0.596	2.112	6.321	71.9	0.470	1.298	5.097	128.9	0.532	1.927	6.252	85.9
H9807079	80/20 blend	0.419	2.364	7.523	78.9	0.558	2.112	6.128	89.7	0.494	1.305	4.944	153.6	0.512	1.943	6.091	105.0
	80/20 blend Ave.	0.403	2.308	7.471	73.2	0.533	2.073	6.192	85.9	1.360	1.245	4.988	142.0	0.480	1.895	6.126	98.7
H9806005	100% BioD	0.270	2.177	7.233	103.1	0.194	1.775	6.197	89.0	0.183	1.014	5.067	162.2	0.207	1.649	6.101	112.0
H9806007	100% BioD	0.227	2.052	7.608	86.6	0.196	1.795	6.303	114.7	0.237	1.084	5.287	206.1	0.214	1.653	6.294	134.0
H9808026	100% BioD	0.224	2.216	7.980	56.9	0.165	1.956	6.764	57.5	0.181	1.161	5.623	115.3	0.182	1.791	6.702	73.3
H9808028	100% BioD	0.240	2.253	8.004	80.5	0.194	1.944	6.728	90.6	0.184	1.140	5.667	159.9	0.201	1.787	6.701	107.6
	100% BioD Ave.	0.240	2.175	7.706	81.8	0.187	1.868	6.498	88.0	0.196	1.100	5.411	160.9	0.201	1.720	6.45	106.7
H9808022	Fischer-T.	0.344	2.295	7.947	44.1	0.425	2.208	6.697	47.8	0.363	1.336	5.455	63.3	0.391	1.987	6.615	51.3
H9808024	Fischer-T.	0.275	2.178	7.762	45.4	0.428	2.234	6.501	50.5	0.377	1.350	5.280	72.7	0.383	1.980	6.427	55.6
	Fischer-T. Ave.	0.310	2.237	7.855	44.7	0.427	2.221	6.599	49.2	0.370	1.343	5.368	68.0	0.387	1.984	6.521	53.4

Appendix A. FTP Emissions Results (CONTINUED)

1990 Dodge 250 PU		Bag 1				Bag 2				Bag 3				Weighted			
		THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.
Test #	Fuel	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi
H9807008	RFD	0.818	2.382	6.414	209.4	0.952	2.090	7.165	154.4	0.744	1.725	5.369	201.5	0.868	2.051	6.517	178.7
H9807009	RFD	0.920	2.479	6.411	239.7	1.009	2.165	7.083	166.5	0.766	1.761	5.205	233.9	0.924	2.119	6.429	200.1
H9808021	RFD	0.903	2.394	6.213	203.4	1.006	2.140	7.169	157.7	0.797	1.771	5.245	212.3	0.928	2.091	6.444	182.1
H9808023	RFD	1.012	2.383	6.147	250.3	1.084	2.172	7.086	180.2	0.832	1.781	5.218	243.9	1.000	2.109	6.379	212.2
	RFD Ave.	0.913	2.410	6.296	225.7	1.013	2.142	7.126	164.7	0.785	1.760	5.259	222.9	0.930	2.093	6.442	193.3
H9807021	80/20 blend	1.031	2.495	6.184	585.2	1.214	2.245	6.750	485.6	0.875	1.772	5.027	473.7	1.083	2.167	6.16	502.9
H9807023	80/20 blend	0.989	2.469	6.306	469.4	1.208	2.257	7.099	481.0	0.869	1.784	5.281	524.4	1.070	2.171	6.436	490.5
H9808025	80/20 blend	1.042	2.514	6.272	462.0	1.227	2.314	6.953	412.4	0.904	1.820	5.244	407.8	1.100	2.220	6.343	421.4
H9808027	80/20 blend	1.094	2.485	6.184	477.7	1.345	2.329	6.852	460.3	0.968	1.808	5.246	434.8	1.190	2.218	6.274	456.9
	80/20 blend Ave.	1.039	2.491	6.237	498.6	1.249	2.286	6.914	459.8	0.904	1.796	5.200	460.2	1.111	2.194	6.303	467.9
H9807011	100% BioD	0.600	2.641	6.460	789.7	0.883	2.308	7.780	777.0	0.561	1.772	6.046	654.0	0.736	2.23	7.032	745.9
H9807026	100% BioD	0.836	2.664	6.716	983.6	1.067	2.396	7.866	871.4	0.729	1.880	6.014	793.5	0.927	2.310	7.121	873.3
H9808040	100% BioD	0.529	2.731	6.381	715.0	0.688	2.332	7.294	792.8	0.499	1.820	5.721	671.8	0.603	2.274	6.674	743.6
H9808041	100% BioD	0.580	2.720	6.968	980.1	0.802	2.309	7.996	1033.1	0.539	1.831	5.944	769.2	0.684	2.263	7.221	949.8
	100% BioD Ave.	0.636	2.689	6.631	867.1	0.860	2.336	7.734	868.6	0.582	1.826	5.931	722.1	0.738	2.269	7.012	828.1
H9808036	Fischer-T.	0.811	2.295	6.049	256.4	0.917	2.042	6.484	233.4	0.702	1.670	4.899	274.2	0.836	1.993	5.959	249.3
H9808037	Fischer-T.	0.912	2.331	5.701	348.8	0.987	2.093	6.110	294.8	0.724	1.678	4.725	329.2	0.900	2.028	5.646	315.4
	Fischer-T. Ave.	0.862	2.313	5.875	302.6	0.952	2.068	6.297	264.1	0.713	1.674	4.812	301.7	0.868	2.011	5.803	282.4

1988 Ford 250		Bag 1				Bag 2				Bag 3				Weighted			
		THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.	THC	CO	NO_x	Parts.
Test #	Fuel	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	mg/mi
H9808035	RFD	0.410	1.947	5.022	376.3	0.282	1.360	7.343	202.2	0.336	1.383	5.745	403.0	0.323	1.487	6.427	293.1
H9808038	RFD	0.480	2.075	4.843	524.9	0.224	1.394	6.94	263.7	0.303	1.377	5.487	448.7	0.299	1.530	6.108	368.4
H9809006	RFD	0.460	1.741	5.287	502.1	0.343	1.224	7.416	293.0	0.384	1.312	5.946	518.0	0.379	1.355	6.573	398.0
	RFD Ave.	0.452	1.921	5.051	467.8	0.283	1.326	7.233	253.0	0.341	1.357	5.726	456.6	0.334	1.457	6.369	353.2
H9808039	80/20 blend	0.412	1.877	5.054	469.6	0.209	1.26	7.307	262.9	0.321	1.288	5.728	499.7	0.282	1.395	6.407	370.7
H9808042	80/20 blend	0.480	1.953	5.003	608.8	0.218	1.235	7.088	298.2	0.352	1.314	5.646	551.1	0.309	1.405	6.262	431.6
H9809010	80/20 blend	0.470	1.781	5.222	NA	0.248	1.188	7.367	NA	0.362	1.269	5.862	NA	0.325	1.333	6.511	NA
	80/20 blend Ave.	0.454	1.870	5.093	539.2	0.225	1.228	7.254	280.5	0.345	1.290	5.745	525.4	0.305	1.378	6.393	401.1
H9808053	100% BioD	0.387	1.583	5.437	572.0	0.215	1.205	7.528	274.5	0.317	1.155	6.053	537.4	0.278	1.269	6.692	407.9
H9809001	100% BioD	0.458	1.603	5.556	652.4	0.242	1.246	7.942	285.0	0.366	1.198	6.334	579.1	0.321	1.307	7.007	441.8
H9809014	100% BioD	0.490	1.598	5.908	694.1	0.261	1.188	8.455	287.7	0.388	1.175	6.757	581.7	0.343	1.269	7.462	452.5
	100% BioD Ave.	0.445	1.595	5.634	639.5	0.239	1.213	7.975	282.4	0.357	1.176	6.381	566.0	0.314	1.282	7.054	434.1
H9808049	Fischer-T.	0.446	1.828	4.742	537.1	0.209	1.178	7.284	286.6	0.342	1.279	6.009	538.9	0.294	1.340	6.409	407.5
H9808051	Fischer-T.	0.453	1.865	5.103	538.4	0.224	1.240	7.145	271.8	0.332	1.298	5.694	490.9	0.301	1.386	6.324	387.1
	Fischer-T. Ave.	0.450	1.847	4.923	537.8	0.217	1.209	7.215	279.2	0.337	1.289	5.852	514.9	0.298	1.363	6.367	397.3

Appendix B1 Detailed Hydrocarbon Speciation Results

C_1-C_{12}

	90 Dodge RFD mg/mi	90 Dodge Fischer-T mg/mi	90 Dodge 80/20 mg/mi	90 Dodge 100% Bio mg/mi	88 Ford RFD mg/mi	88 Ford Fischer-T mg/mi	88 Ford 80/20 mg/mi	88 Ford 100% Bio mg/mi
Methane by FID	3.986	13.287	11.206	-0.098	351.505	295.256	303.773	342.630
NMHC by FID	995.773	886.569	1178.926	805.035	355.787	297.527	302.445	353.854
NMHC by GC	266.464	249.101	309.441	265.234	139.402	135.308	133.594	161.748
Alkanes								
Normal Alkanes								
Methane	18.2825	16.6327	19.8424	6.574	1.841	0.8481	2.615	0.9082
Ethane	1.0153	1.9498	1.8496	2.119	0.327	0.4084	0.231	0.2073
Propane	0.0968	0.2759	0.2441	0.416	0.000	0.0000	0.028	0.0214
Butane	0.1967	0.0000	0.2324	0.141	0.002	0.0337	0.009	0.0548
Pentane	0.0706	0.0033	0.0000	0.043	0.012	0.0119	0.001	0.0482
Hexane	0.9159	0.1397	0.5810	1.165	0.589	0.1717	0.534	0.8622
Heptane	0.0933	0.0000	0.6960	0.213	0.187	0.0000	0.037	0.2056
Octane	0.0000	0.0000	0.0000	0.000	0.034	0.0000	0.000	0.0752
Nonane	0.0000	0.0000	0.0000	0.230	0.000	0.0000	0.000	0.0000
Decane	0.9080	0.0000	0.8637	0.000	0.049	0.0000	0.085	0.3716
Undecane	1.6610	0.7167	0.6613	0.046	0.430	0.0808	0.594	1.2896
Dodecane	1.1873	1.5099	0.1649	0.146	0.706	0.5993	1.337	3.0801
Branched Alkanes								
2-Methylpropane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2,2-Dimethylpropane	0.0000	0.8607	0.0000	0.501	0.120	0.3010	0.230	0.2325
2-Methylbutane	0.1598	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2,2-Dimethylbutane	0.3653	0.3659	0.4994	0.267	0.120	0.2113	0.511	0.3085
2,3-Dimethylbutane	0.5142	0.0000	0.0000	0.248	0.081	0.2337	0.432	0.3824
2-Methylpentane	0.0000	0.1045	0.0000	0.000	1.856	0.0000	0.463	1.0896
3-Methylpentane	0.1501	1.6432	0.2996	0.175	0.880	0.3716	0.798	0.5342
2,2,3-Trimethylbutane	0.4233	0.0826	0.5314	0.485	0.301	0.2505	0.264	0.5195
2,2-Dimethylpentane	0.4936	0.0000	0.0000	0.151	0.000	0.0000	0.068	0.0000
2,3-Dimethylpentane	0.2643	0.8220	0.2985	0.150	0.404	0.2424	0.421	0.4068
2,4-Dimethylpentane	0.3919	0.4224	0.1811	0.145	0.435	0.1918	0.381	0.2631
3,3-Dimethylpentane	0.0000	0.1204	0.0000	0.000	0.047	0.0776	0.000	0.0967
2-Methylhexane	0.1653	0.3859	0.1918	0.080	0.458	0.0000	0.074	0.0227
3-Methylhexane	1.2537	1.2790	0.3878	2.091	0.638	0.8662	0.977	1.1101
2,2,4-Trimethylpentane (i-Octane)	1.3666	0.8299	2.0997	1.529	0.679	0.0000	0.889	0.4836
2,3,3-Trimethylpentane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2,3,4-Trimethylpentane	0.0000	0.1932	0.0000	0.000	0.000	0.0000	0.000	0.0000
3-Ethylpentane	0.1881	0.6356	0.1555	0.326	0.189	0.1773	0.167	0.2568
2,2-Dimethylhexane	0.1584	0.6535	0.0000	0.081	0.000	0.0000	0.055	0.0000
2,3-Dimethylhexane	0.0000	0.1008	0.1140	0.414	0.064	0.3074	0.050	0.3090
2,4-Dimethylhexane	0.0664	0.0000	0.0000	0.072	0.106	0.0000	0.082	0.0000
2,5-Dimethylhexane	0.0000	0.0000	0.0000	0.000	0.038	0.0000	0.000	0.0000
3,3-Dimethylhexane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2-Methylheptane	0.0000	0.1918	0.0774	0.074	0.148	0.0953	0.000	0.1851
3-Methylheptane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0572
4-Methylheptane	0.0000	0.5952	0.0000	0.045	0.087	0.0000	0.183	0.0555
2,3-Dimethylheptane	0.7467	0.0000	0.6409	0.000	0.000	0.0000	0.000	0.0000
2,4-Dimethylheptane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000

	90 Dodge RFD mg/mi	90 Dodge Fischer-T mg/mi	90 Dodge 80/20 mg/mi	90 Dodge 100% Bio mg/mi	88 Ford RFD mg/mi	88 Ford Fischer-T mg/mi	88 Ford 80/20 mg/mi	88 Ford 100% Bio mg/mi
3,5-Dimethylheptane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2,2,5-Trimethylhexane	0.0000	0.1096	0.0000	0.000	0.045	0.0656	0.000	0.0552
2,3,5-Trimethylhexane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2-Methyloctane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
3-Methyloctane	0.4007	0.0000	0.0000	0.029	0.000	0.0000	0.000	0.0000
2,2-Dimethyloctane	0.0000	0.0000	0.0000	0.050	0.000	0.0000	0.000	0.0000
2,4-Dimethyloctane	1.1900	0.5949	0.8099	0.712	0.743	0.2220	0.352	0.6466
Cyclo Alkanes								
Cyclopentane	1.0801	0.0000	0.9592	0.496	1.342	1.4947	0.601	1.9175
Methylcyclopentane	0.8179	0.3566	0.0000	0.543	0.000	0.0000	0.000	0.2471
Cyclohexane	0.0256	0.2871	0.0000	0.022	0.123	0.0000	0.000	0.0631
t-1,2-Dimethylcyclopentane	0.0000	0.0774	0.0000	0.000	0.000	0.0000	0.000	0.0000
c-1,3-Dimethylcyclopentane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
Methylcyclohexane	0.1092	0.1249	0.1471	0.067	0.268	0.0000	0.000	0.0349
1c,2t,3-Trimethylcyclopentane	0.7714	0.1425	1.9119	4.403	0.000	0.4131	0.141	0.7146
c-1,2-Dimethylcyclohexane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
c-1,3-Dimethylcyclohexane	0.0000	0.6324	0.0000	0.000	0.734	0.3616	0.451	0.6945
t-1,3-Dimethylcyclohexane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
t-1,4-Dimethylcyclohexane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
Ethylcyclohexane	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
Alkenes								
Ethene	48.4947	54.2483	63.1385	88.440	43.150	47.2717	44.936	50.9529
Propene	17.2334	20.9819	19.2698	18.133	14.629	16.5609	14.962	15.7007
1-Butene	0.0000	5.1742	0.0000	4.018	1.837	3.9731	3.533	4.1406
c-2-Butene	0.0000	0.0000	0.0000	0.129	0.000	0.0000	0.000	0.0000
t-2-Butene	0.0000	1.1675	0.0000	0.216	0.275	0.6631	0.325	0.3276
2-Methylpropene	3.9487	4.0935	3.7041	3.534	2.924	3.0246	2.855	2.6353
1-Pentene	2.0347	1.1277	1.4864	1.658	0.893	0.6669	1.712	1.2702
c-2-Pentene	0.0000	0.5128	0.4569	0.200	0.069	0.1080	0.038	0.4502
t-2-Pentene	0.4988	0.6369	0.5499	0.392	0.141	1.5232	0.937	0.0997
2-Methyl-1-Butene	0.6505	0.7396	0.1508	0.056	0.115	0.6430	0.615	1.1201
3-Methyl-1-Butene	0.0000	0.1982	0.3882	0.000	0.430	0.0000	0.000	0.2594
2-Methyl-2-Butene	0.3320	0.5249	0.0000	0.000	0.063	0.0772	0.000	0.0566
1-Hexene	0.8724	0.3986	1.3970	4.026	1.472	0.6438	0.707	1.2699
c-2-Hexene	0.0707	0.0000	0.0000	0.000	0.289	0.0000	0.082	0.4136
t-2-Hexene	0.5530	0.4105	1.4584	0.052	0.029	0.0735	0.077	0.0884
c-3-Hexene	0.2044	0.0754	1.6902	0.920	0.071	0.1144	0.147	0.0000
t-3-Hexene	0.0791	0.0000	0.1247	8.316	0.106	0.1316	0.057	0.6775
2-Methyl-1-Pentene	0.1877	0.5177	0.0000	0.034	0.000	0.4045	0.000	0.6568
3-Methyl-1-Pentene	0.3742	1.2263	0.4026	0.702	1.103	0.4665	0.826	0.3171
4-Methyl-1-Pentene	0.0000	1.5691	0.6273	0.412	0.743	0.0978	0.444	0.6837
2-Methyl-2-Pentene	0.0699	0.2178	0.4262	0.000	0.000	0.1575	0.000	0.0000
3-Methyl-c-2-Pentene	0.9766	0.8073	1.1436	1.335	0.506	0.9257	0.537	0.9286
3-Methyl-t-2-Pentene	0.0000	0.0585	0.1113	0.269	0.040	0.0697	0.000	0.0000
4-Methyl-c-2-Pentene	0.0000	0.0000	0.0000	0.000	0.122	0.0000	0.000	0.0790
4-Methyl-t-2-Pentene	0.9457	1.7575	0.7285	1.034	1.170	0.9170	2.976	0.3436
3,3-Dimethyl-1-Butene	0.8762	0.0000	1.0103	0.000	0.186	0.7606	0.101	0.8339
1-Heptene	0.0000	0.3979	0.1666	1.711	0.343	0.3474	0.247	0.8200
c-2-Heptene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
t-2-Heptene	0.0000	0.3652	0.0000	0.063	0.032	0.0000	0.000	0.0552
t-3-Heptene	0.0000	0.0000	0.8956	3.704	0.000	0.0000	0.032	0.3210

	90 Dodge RFD mg/mi	90 Dodge Fischer-T mg/mi	90 Dodge 80/20 mg/mi	90 Dodge 100% Bio mg/mi	88 Ford RFD mg/mi	88 Ford Fischer-T mg/mi	88 Ford 80/20 mg/mi	88 Ford 100% Bio mg/mi
2,3-Dimethyl-2-Pentene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
3,4-Dimethyl-1-Pentene	0.0000	0.0000	0.0000	0.000	0.030	0.0000	0.000	0.0807
3-Methyl-1-Hexene	5.7118	0.1297	5.2328	0.000	0.031	2.7156	1.589	1.7706
2-Methyl-2-Hexene	0.5460	0.0808	0.0000	0.060	0.000	0.0000	0.000	0.2845
3-Methyl-t-3-Hexene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
1-Octene	0.8202	0.5305	1.1722	1.102	0.484	0.3648	0.344	0.5331
c-2-Octene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
t-2-Octene	0.0000	0.0000	0.0000	0.333	0.035	0.0000	0.078	0.0000
t-4-Octene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2,4,4-Trimethyl-1-Pentene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2,4,4-Trimethyl-2-Pentene	0.0000	0.0000	0.0000	0.054	0.000	0.0000	0.000	0.0000
3-Ethyl-c-2-Pentene	0.0000	0.0753	0.0000	0.000	0.000	0.0000	0.000	0.0000
1-Nonene	0.6169	0.0873	0.6950	0.592	0.194	0.2689	0.252	0.2425
Propadiene	0.4140	0.5044	0.1251	0.231	0.297	0.5040	0.236	0.2347
1,3-Butadiene	3.8474	3.7828	5.2915	8.416	4.482	4.9698	4.585	5.6366
2-Methyl-1,3-Butadiene	0.1832	1.6704	0.7569	1.144	0.600	0.4206	0.473	0.6568
Cyclopentadiene	0.2059	0.4977	0.3590	0.679	0.313	0.1244	0.141	0.0779
Cyclopentene	0.0651	0.0599	0.2072	0.873	0.161	0.1621	0.221	0.2245
1-Methylcyclopentene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
3-Methylcyclopentene	0.0720	0.0790	0.0000	0.000	0.000	0.0000	0.000	0.0000
Cyclohexene	0.0673	0.0000	0.1665	0.482	0.127	0.0540	0.044	0.2264
Alkynes								
Ethyne	13.8633	13.1128	16.4079	20.570	7.667	8.0246	7.759	7.3247
Propyne	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.1333
1-Butyne	0.6054	0.0000	0.0000	0.039	0.000	0.0000	0.044	0.0820
2-Butyne	0.2877	4.1477	2.8053	1.729	1.013	0.6665	2.631	0.5729
Aromatic Hydrocarbons								
Benzene	1.5746	4.9879	4.1880	13.424	3.991	1.3117	2.724	2.4785
Toluene	3.0113	1.7620	3.5224	2.298	1.814	1.5803	1.785	2.1712
Ethylbenzene	0.4665	0.5354	0.6883	0.490	0.351	0.1866	0.103	0.2466
o-Xylene	0.7568	0.1283	0.8868	0.021	0.300	0.0000	0.155	0.2729
m&p-Xylene	0.2178	0.1675	0.4782	0.358	0.172	0.2864	0.251	0.6765
n-Propylbenzene	0.9582	0.0000	1.1643	0.299	0.041	0.0000	0.029	0.0532
i-Propylbenzene	0.0000	0.0000	0.0000	0.032	0.000	0.0000	0.000	0.0000
1-Methyl-2-ethylbenzene	1.3026	0.0000	1.3654	0.029	0.000	0.0000	0.000	0.0000
1-Methyl-3-ethylbenzene	2.8313	0.3778	5.6033	0.599	0.316	0.0000	0.344	0.2483
1-Methyl-4-ethylbenzene	0.4274	0.0000	2.3392	0.599	0.219	0.0000	0.033	0.0691
1,2-Dimethyl-3-ethylbenzene	0.1930	0.0000	2.0939	0.193	0.000	0.0000	0.000	0.0000
1,2-Dimethyl-4-ethylbenzene	4.1976	0.2275	4.6373	0.428	0.000	0.0000	0.000	0.2321
1,3-Dimethyl-2-ethylbenzene	0.3962	0.0000	0.4825	0.828	0.028	0.0000	0.031	0.0609
1,3-Dimethyl-4-ethylbenzene	0.4179	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
1,4-Dimethyl-2-ethylbenzene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
1,2,3-Trimethylbenzene	0.4179	0.0000	1.8691	0.058	0.000	0.0000	0.000	0.0520
1,2,4-Trimethylbenzene	6.3436	0.9371	7.0024	1.006	0.722	0.2381	0.824	0.9274
1,3,5-Trimethylbenzene	2.0459	0.4455	2.4688	0.314	0.028	0.0000	0.000	0.0567
Indan	0.1182	0.0000	0.0000	0.000	0.000	0.0000	0.015	0.0000
i-Butylbenzene	19.9883	1.3225	22.4334	1.307	1.143	0.0000	1.023	0.0559
s-Butylbenzene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
2-Methyl-Butylbenzene	0.6423	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
tert-1-Butyl-2-Methyl-Benzene	0.0000	0.2091	0.0000	0.000	0.000	0.0000	0.000	0.0000
tert-1-Butyl-3,5-Dimethyl-	2.8736	1.4618	3.9550	0.100	0.000	0.0000	0.000	0.0000

	90 Dodge RFD mg/mi	90 Dodge Fischer-T mg/mi	90 Dodge 80/20 mg/mi	90 Dodge 100% Bio mg/mi	88 Ford RFD mg/mi	88 Ford Fischer-T mg/mi	88 Ford 80/20 mg/mi	88 Ford 100% Bio mg/mi
Benzene								
1,2-Diethylbenzene	1.0115	0.0000	0.6945	0.000	0.030	0.0000	0.000	0.0000
1,3-Diethylbenzene	1.9536	0.0000	2.2680	0.447	0.087	0.0000	0.045	0.0871
1,4-Diethylbenzene	4.6291	0.0000	5.7308	0.194	0.000	0.0000	0.000	0.0000
1-Methyl-2-n-Propylbenzene	4.9108	0.0895	5.6006	0.343	0.093	0.0000	0.034	0.0000
1-Methyl-3-n-Propylbenzene	0.6046	0.1235	0.0000	0.152	0.068	0.0000	0.043	0.0704
1-Methyl-4-n-Propylbenzene	0.8146	0.0588	1.2824	0.034	0.052	0.0000	0.000	0.1020
1-Methyl-2-i-Propylbenzene	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
1-Methyl-3-i-Propylbenzene	1.8439	0.0000	0.8712	0.037	0.000	0.0000	0.000	0.0000
1-Methyl-4-i-Propylbenzene	0.6243	0.0000	0.6587	0.000	0.000	0.0000	0.000	0.0000
1,2,3,4-Tetramethylbenzene	0.0000	0.9663	0.0000	0.090	0.000	0.0805	0.000	0.0000
1,2,3,5-Tetramethylbenzene	0.1229	0.1769	0.6815	0.000	0.000	0.0000	0.000	0.0000
1,2,4,5-Tetramethylbenzene	4.8608	3.9017	3.6819	5.231	4.080	4.7058	4.261	6.0940
n-Pent-Benzene	0.0776	1.1736	0.0000	0.000	0.043	0.0000	0.000	0.0000
Styrene	1.2998	0.8929	1.7157	2.331	0.840	0.1795	0.447	0.8337
Naphthalene	0.9994	1.1927	1.2209	0.282	0.190	0.0000	0.000	0.4133
Ethers								
Methyl-t-Butyl-Ether	0.1776	1.1626	0.0723	0.000	0.000	0.0000	0.000	0.0000
Ethyl-t-Butyl-Ether	0.0000	0.0000	0.0000	0.000	0.000	0.0000	0.000	0.0000
Unknowns								
Unknown (C1-C4)	10.2788	5.1940	11.0035	5.996	7.191	3.1137	3.647	2.6557
Unknown (C4-C12)	60.1167	83.4332	61.6366	34.380	19.188	18.5396	12.814	24.4042

Appendix B2 Detailed Hydrocarbon Speciation Results

C_8-C_{20}

Compound	MW	C #	88 Ford RFD mg/mi	88 Ford Fischer T mg/mi	88 Ford 80/20 mg/mi	88 Ford 100% BioD mg/mi
Total C_8-C_{20}			4.620	3.749	5.179	4.072
Ethylbenzene	106.17	8	0.043	0.037	0.060	0.052
m&p-xylene	106.17	8	0.049	0.061	0.115	0.075
Cyclohexanone	98.15	6	0.212	0.151	0.180	0.169
2-methyloctane	120.2	9	0.076	0.086	0.098	0.104
2-heptanone	114.19	7	0.064	0.064	0.070	0.073
3-methyloctane	120.2	9	0.000	0.006	0.024	0.008
Styrene	104.15	8	0.104	0.060	0.084	0.064
Heptanal	114.19	7	0.008	0.013	0.043	0.021
o-xylene	106.17	8	0.028	0.027	0.051	0.030
1-nonene	126.24	9	0.115	0.073	0.109	0.111
Nonane	128.26	9	0.014	0.010	0.021	0.020
Isopropylbenzene	120.2	9	0.006	0.000	0.004	0.003
Propylcyclohexane	126.24	9	0.075	0.080	0.085	0.102
Benzaldehyde*	106.12	7	2.109	2.062	2.223	2.090
Dimethyloctane	142.28	10	0.009	0.001	0.004	0.011
Propylbenzene	120.2	9	0.024	0.011	0.025	0.017
m-ethyltoluene	120	9	0.055	0.015	0.064	0.034
p-ethyltoluene	120.2	9	0.017	0.002	0.029	0.010
1,3,5-trimethylbenzene	120.2	9	0.030	0.002	0.036	0.011
Phenol	94.11	6	0.045	-0.040	0.031	0.072
o-ethyltoluene	120	9	0.023	0.004	0.025	0.008
t-butylbenzene	134.22	10	0.009	0.004	0.012	0.005
Octanal	128.22	8	0.014	0.006	0.009	0.006
1,2,4-trimethylbenzene	120.2	9	0.066	0.009	0.084	0.017
4-methylstyrene	118.18	9	0.004	0.003	0.008	0.006
1,3-dichlorobenzene	146	6	0.004	0.006	0.009	0.003
1-decene	140.27	10	0.069	0.051	0.070	0.075
Isobutylbenzene	134.22	10	0.340	0.012	0.337	0.053
Decane	142.29	10	-0.001	0.005	0.020	0.010
Sec-butylbenzene	134.22	10	-0.004	0.002	0.007	0.003
1,2,3-trimethylbenzene	120.2	9	0.009	0.001	0.011	0.004
m-isopropyltoluene	134.22	10	0.006	0.002	0.008	0.003
p-isopropyltoluene	134.22	10	-0.002	0.000	0.001	0.000
Indan	118.18	9	0.008	0.000	0.008	0.005
Indene	116	9	0.007	0.002	0.005	0.007
o-isopropyltoluene	134.22	10	0.009	0.010	0.012	0.007
o-methylphenol	108	7	0.002	-0.007	0.013	-0.005
1,3-diethylbenzene	134.22	10	0.009	-0.001	0.021	0.001
Acetophenone*	120.15	8	0.496	0.468	0.513	0.404
m-tolualdehyde*	120	8	0.021	0.002	0.013	0.008
4-n-propyltoluene + 1,4-diethylbenzene	134.22	10	0.002	0.005	0.010	0.005
Butylbenzene	134.22	10	0.008	0.006	0.008	0.009
5-ethyl-m-xylene	134.22	10	0.006	0.004	0.009	0.006
1,2-diethylbenzene	134.22	10	0.025	0.001	0.010	-0.004
m/p-methylphenol	108.14	7	0.003	0.016	0.000	0.000
2-n-propyltoluene	134.22	10	0.001	0.019	0.024	0.026

Appendix B2 Detailed Hydrocarbon Speciation Results

C_8-C_{20} (CONTINUED)

Compound	MW	C #	x	88 Ford RFD mg/mi	88 Ford Fischer T mg/mi	88 Ford 80/20 mg/mi	88 Ford 100% BioD mg/mi
Total C8-C20				4.620	3.749	5.179	4.072
2-ethyl-p-xylene	134.22	10		0.013	0.011	0.017	0.013
4-ethyl-o-xylene	134.22	10		0.003	0.000	0.006	0.003
4-tert-butyltoluene	148.24	11		0.002	0.011	0.000	0.004
Nonanal	142.24	9		-0.034	-0.037	-0.020	-0.050
1-undecene	154.3	11		0.036	0.012	0.029	0.027
2-methylbenzofuran	132.13	9		0.009	0.007	0.021	0.007
Undecane	156.31	11		0.018	0.011	0.031	0.013
5-isopropyl-m-xylene	148.24	11		0.001	0.001	0.002	0.003
1,2,4,5-tetramethylbenzene	134.19	10		0.001	0.001	0.002	-0.001
1,2,3,5-tetramethylbenzene	134.19	10		0.001	0.002	0.005	0.001
Isoamylbenzene	148.24	11		0.000	0.002	0.000	0.001
2-methylindan	132.21	10		-0.002	0.001	-0.004	-0.004
1-methylindan	132.21	10		-0.004	-0.005	-0.005	-0.006
1,2,3,4-tetramethylbenzene	134.22	10		0.000	0.001	0.002	0.001
Pentylbenzene	148.25	11		0.004	0.002	0.004	0.003
1,2,3,4-tetrahydronaphthalene	132.21	10		-0.001	-0.002	0.000	-0.001
1,2-dihydronaphthalene	130.19	10		0.009	0.004	0.006	-0.001
1,4-diisopropylbenzene	162.28	12		0.000	0.000	0.000	0.000
Naphthalene	128.17	10		0.038	0.034	0.041	0.028
A-dimethylindane	146.23	11		0.001	-0.002	0.000	-0.001
B-dimethylindane	146.23	11		0.002	-0.005	0.000	-0.003
C-dimethylindane	146.23	11		0.000	-0.002	0.000	-0.001
D-dimethylindan	146.23	11		0.000	-0.002	0.000	-0.001
Dodecene	170.34	12		0.011	0.001	-0.004	0.004
Dodecane	142.29	12		0.011	0.018	0.021	0.010
Pentamethylbenzene	148.25	11		0.001	0.000	-0.001	0.002
2-methylnaphthalene	142.2	11		0.010	0.005	0.012	0.005
1-methylnaphthalene	142.2	11		0.006	0.002	0.005	0.003
Tridecane	184.37	13		0.005	0.011	0.014	0.009
Biphenyl	154.21	12		0.007	0.002	0.007	0.000
Tetradecane	198.4	14		0.046	0.021	0.083	0.021
Pentadecane	212.42	15		0.036	0.019	0.056	0.015
Hexadecane	226.45	16		0.010	0.018	0.021	0.015
Heptadecane	240.48	17		0.015	0.032	0.035	0.035
Octadecane	254.5	18		0.034	0.057	0.049	0.061
Nonadecane	268.53	19		0.059	0.110	0.075	0.072
Eicosane	282.56	20		0.051	0.054	0.043	0.048

*= suspect: these species are possibly affected by Tenax decomposition artifact. They were retained in this data set, since they were not observed in the media blank and, though they were observed in the ambient background samples, the exhaust sample concentrations of benzaldehyde and acetophenone were many times higher than the ambient background concentration.

Appendix B3 Detailed Hydrocarbon Speciation Results

Carbonyl

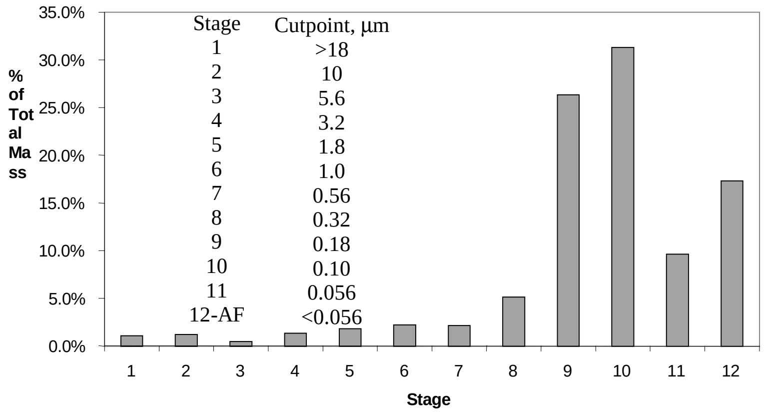
Vehicle	**90 Dodge**	**90 Dodge**	**90 Dodge**	**90 Dodge**	**88 Ford**	**88 Ford**	**88 Ford**	**88 Ford**
Fuel	**RFD**	**Fischer-T.**	**80/20**	**100% Bio**	**RFD**	**Fischer-T.**	**80/20**	**100% Bio**
	g/mi	**g/mi**	**g/mi**	**g/mi**	**g/mi**	**g/mi**	**g/mi**	**g/mi**
Phase 1 total	0.121	0.126	0.215	0.145	0.116	0.135	0.134	0.142
Phase 2 total	0.120	0.139	0.152	0.176	0.109	0.105	0.102	0.111
Phase 3 total	0.098	0.095	0.104	0.108	0.117	0.110	0.115	0.118
FTP weighted	**0.114**	**0.125**	**0.153**	**0.151**	**0.113**	**0.113**	**0.112**	**0.119**
Formaldehyde	0.0633	0.0593	0.0680	0.0809	0.0566	0.0596	0.0575	0.0639
Acetaldehyde	0.0246	0.0286	0.0415	0.0310	0.0240	0.0258	0.0252	0.0265
Propionaldehyde	0.0043	0.0052	0.0071	0.0067	0.0041	0.0046	0.0044	0.0049
Acrolein	0.0111	0.0104	0.0172	0.0060	0.0079	0.0098	0.0089	0.0076
Methacrolein	0.0019	0.0023	0.0030	0.0016	0.0016	0.0017	0.0016	0.0015
n-Butyraldehyde	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Crotonaldehyde	0.0014	0.0015	0.0021	0.0023	0.0015	0.0014	0.0014	0.0016
Pentanaldehyde	0.0021	0.0014	0.0031	0.0041	0.0027	0.0012	0.0013	0.0014
Hexanaldehyde	0.0008	0.0037	0.0005	0.0083	0.0031	0.0038	0.0041	0.0036
Benzaldehyde	0.0027	0.0034	0.0068	0.0040	0.0045	0.0009	0.0037	0.0022
p-Tolualdehyde	0.0001	0.0049	0.0003	0.0011	0.0025	0.0000	0.0010	0.0001
Acetone	0.0015	0.0012	0.0026	0.0036	0.0020	0.0027	0.0019	0.0034
Butanone	0.0003	0.0026	0.0004	0.0016	0.0020	0.0019	0.0014	0.0024

Appendix C1. Full MOUDI Size Distributions for each Vehicle/Fuel Combination

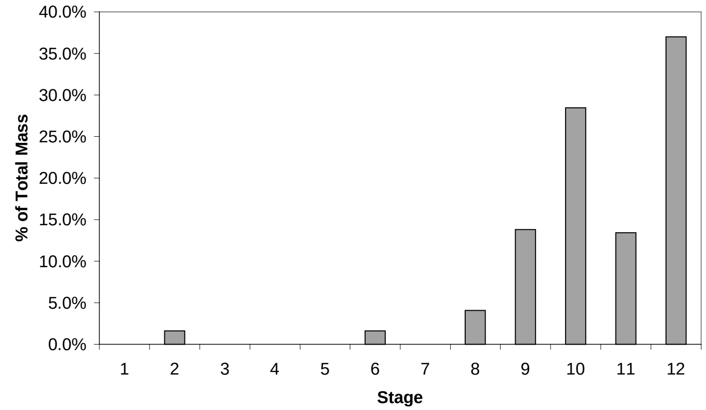
Test #	Year	Make	Model	Fuel	Percentage of Mass for each Cut Point, μm											
					>18	10	5.6	3.2	1.8	1.0	0.56	0.32	0.18	0.10	0.056	<0.056
H9805028	1996	Dodge	Ram	RFD	0.0%	2.1%	0.0%	2.1%	1.7%	1.0%	2.1%	5.6%	25.1%	33.1%	13.9%	13.2%
H9808050	1996	Dodge	Ram	RFD	2.2%	0.3%	0.9%	0.6%	1.9%	3.4%	2.2%	4.7%	27.6%	29.5%	5.3%	21.4%
			Ave	RFD	1.1%	1.2%	0.5%	1.4%	1.8%	2.2%	2.1%	5.1%	26.4%	31.3%	9.6%	17.3%
H9805032	1996	Dodge	Ram	B100	0.0%	1.6%	0.0%	0.0%	0.0%	1.6%	0.0%	4.1%	13.8%	28.5%	13.4%	37.0%
H9805041	1996	Dodge	Ram	80/20	3.8%	0.8%	0.8%	0.0%	0.4%	5.5%	5.1%	8.1%	18.2%	33.1%	13.6%	10.6%
H9808052	1996	Dodge	Ram	F-T	1.0%	0.5%	0.8%	0.5%	0.0%	2.3%	4.1%	9.8%	23.5%	28.2%	8.0%	21.2%
H9805051	1995	Ford	F-350	RFD	0.8%	0.8%	2.1%	0.8%	0.8%	2.1%	2.1%	5.0%	14.6%	36.8%	18.4%	15.5%
H9806005	1995	Ford	F-350	B100	0.3%	0.0%	0.0%	0.0%	0.3%	2.0%	1.8%	4.3%	18.4%	21.2%	11.3%	40.6%
H9806007	1995	Ford	F-350	B100	0.3%	0.5%	0.0%	1.3%	0.0%	4.0%	4.0%	5.6%	17.2%	26.2%	22.0%	19.0%
H9808026	1995	Ford	F-350	B100	0.3%	0.7%	0.0%	1.0%	2.7%	2.1%	3.8%	6.9%	18.9%	29.2%	10.3%	24.1%
			Ave	B100	0.3%	0.4%	0.0%	0.8%	1.0%	2.7%	3.2%	5.6%	18.2%	25.5%	14.5%	27.9%
H9806009	1995	Ford	F-350	80/20	0.2%	0.4%	0.0%	0.6%	0.0%	0.0%	1.1%	43.6%	12.1%	23.5%	10.2%	8.3%
H9806012	1995	Ford	F-350	80/20	0.5%	0.8%	0.8%	0.5%	1.0%	1.0%	3.4%	5.7%	15.7%	29.2%	13.6%	27.7%
H9807079	1995	Ford	F-350	80/20	0.6%	0.0%	0.0%	0.6%	1.6%	2.4%	2.4%	12.0%	38.5%	27.6%	4.6%	9.6%
			Ave	80/20	0.5%	0.4%	0.3%	0.6%	0.9%	1.1%	2.3%	20.5%	22.1%	26.8%	9.5%	15.2%
H9808024	1995	Ford	F-350	F-T	0.0%	0.0%	1.3%	0.4%	2.1%	1.7%	5.9%	8.4%	16.0%	34.6%	7.2%	22.4%
H9807008	1990	Dodge	250	RFD	0.9%	0.0%	0.7%	0.7%	0.9%	2.6%	4.2%	11.9%	31.3%	32.0%	5.1%	9.8%
H9808021	1990	Dodge	250	RFD	0.6%	0.0%	0.0%	0.6%	1.6%	2.4%	2.4%	12.0%	38.5%	27.6%	4.6%	9.6%
			Ave	RFD	0.8%	0.0%	0.3%	0.7%	1.2%	2.5%	3.3%	11.9%	34.9%	29.8%	4.9%	9.7%
H9807011	1990	Dodge	250	B100	0.1%	0.1%	0.2%	0.3%	0.1%	0.4%	0.5%	15.2%	36.5%	10.4%	1.3%	34.9%
H9808041	1990	Dodge	250	B100	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.9%	13.7%	47.3%	25.0%	6.3%	6.7%
			Ave	B100	0.1%	0.1%	0.1%	0.1%	0.1%	0.3%	0.7%	14.4%	41.9%	17.7%	3.8%	20.8%
H9807021	1990	Dodge	250	80/20	0.2%	0.1%	0.1%	0.1%	0.1%	0.7%	3.3%	19.6%	51.5%	18.4%	2.0%	3.9%
H9808025	1990	Dodge	250	80/20	0.4%	0.1%	0.0%	0.2%	0.2%	0.5%	4.3%	20.9%	47.1%	18.4%	2.7%	5.0%
			Ave	80/20	0.3%	0.1%	0.1%	0.1%	0.2%	0.6%	3.8%	20.3%	49.3%	18.4%	2.4%	4.4%
H9808037	1990	Dodge	250	F-T	0.4%	0.1%	0.1%	0.5%	0.5%	1.5%	4.0%	18.6%	45.9%	20.3%	3.5%	4.7%
H9808035	1988	Ford	F250	RFD	0.6%	0.1%	0.0%	0.2%	0.6%	0.8%	2.2%	5.3%	18.7%	18.6%	4.7%	48.1%
H9809006	1988	Ford	F250	RFD	0.1%	0.1%	0.1%	0.3%	0.3%	0.7%	2.4%	6.3%	24.8%	24.1%	6.3%	34.3%
			Ave	RFD	0.4%	0.1%	0.0%	0.2%	0.4%	0.8%	2.3%	5.8%	21.8%	21.4%	5.5%	41.2%
H9809001	1988	Ford	F250	B100	0.1%	0.0%	0.2%	0.2%	0.1%	1.1%	1.9%	4.3%	20.4%	23.3%	7.4%	41.0%
H9809014	1988	Ford	F250	B100	7.7%	0.0%	0.1%	0.1%	0.0%	0.9%	1.4%	2.9%	18.4%	21.4%	6.7%	40.3%
			Ave	B100	3.9%	0.0%	0.2%	0.2%	0.0%	1.0%	1.7%	3.6%	19.4%	22.4%	7.0%	40.7%
H9808039	1988	Ford	F250	80/20	0.4%	0.4%	0.2%	0.0%	0.1%	0.5%	1.9%	5.9%	23.0%	23.1%	5.7%	38.8%
H9809010	1988	Ford	F250	80/20	0.1%	0.0%	0.1%	0.1%	0.3%	0.6%	45.3%	3.4%	13.8%	14.2%	3.6%	18.5%
			Ave	80/20	0.3%	0.2%	0.1%	0.0%	0.2%	0.6%	23.6%	4.7%	18.4%	18.6%	4.7%	28.7%
H9808049	1988	Ford	F250	F-T	0.5%	0.0%	0.0%	0.2%	0.5%	0.8%	1.9%	5.6%	24.2%	25.9%	7.7%	32.7%

Appendix C2. Composite MOUDI Spectra for 1996 Dodge Ram

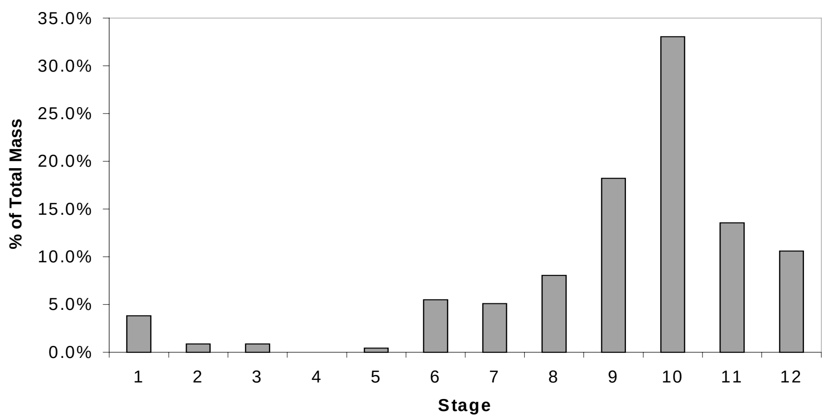
1996 Dodge Ram RFD



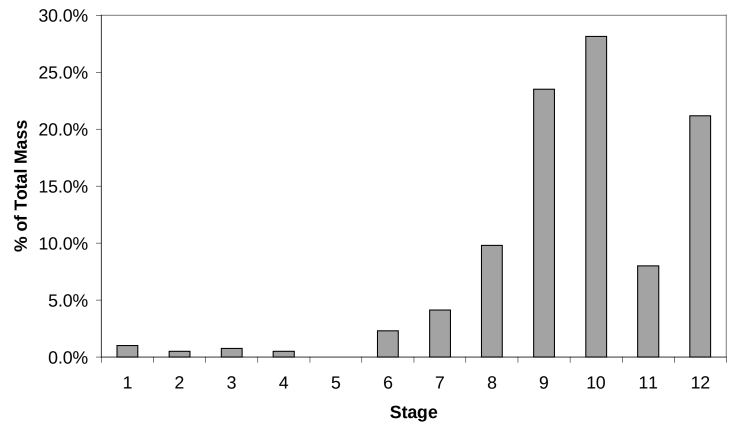
1996 Dodge Ram 100% Biodiesel



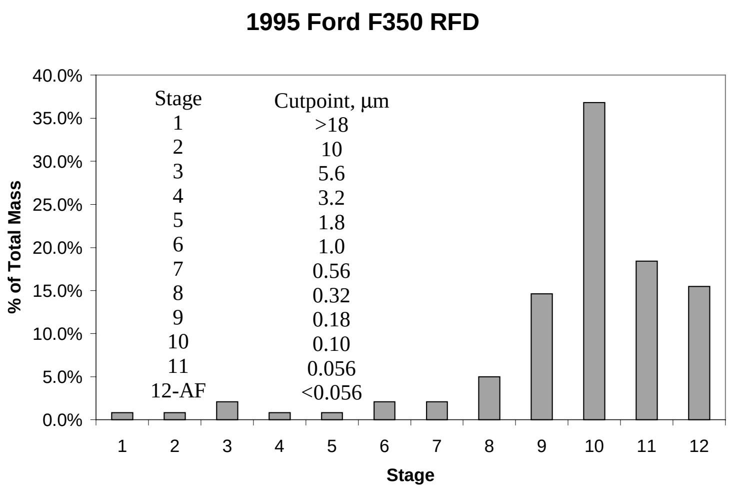
1996 Dodge Ram 80/20 Blend

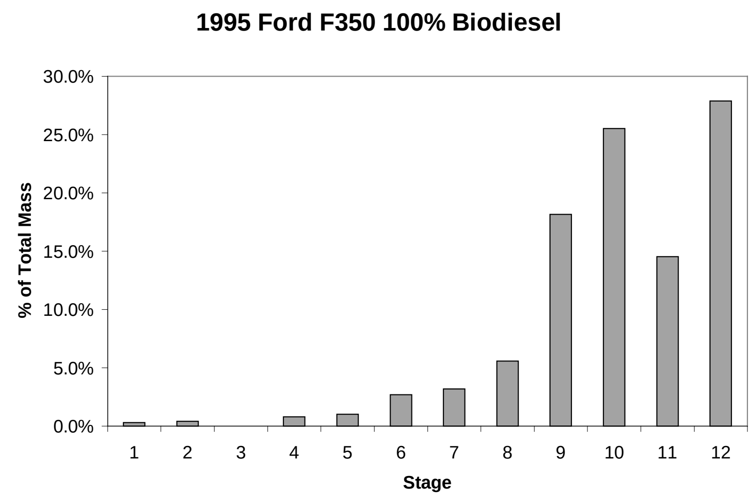


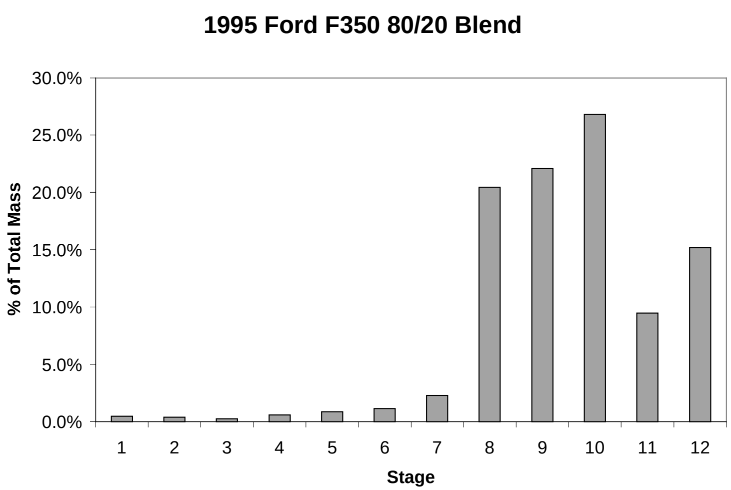
1996 Dodge Ram F-T

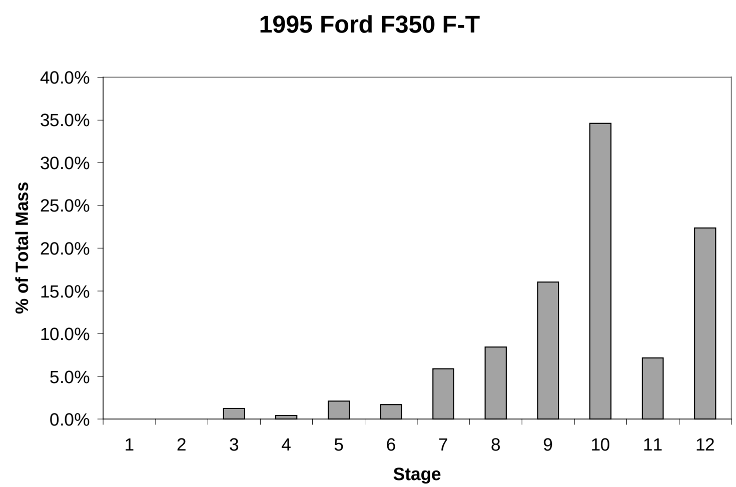


Appendix C2. cont. Composite MOUDI Spectra for 1995 Ford F350

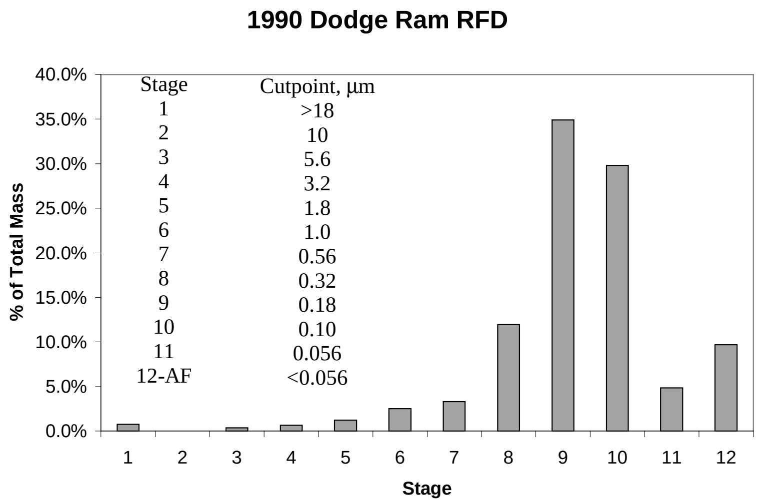


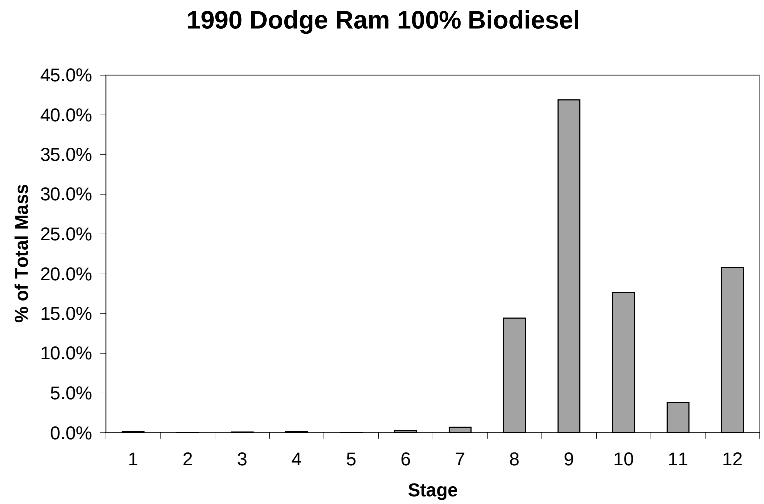


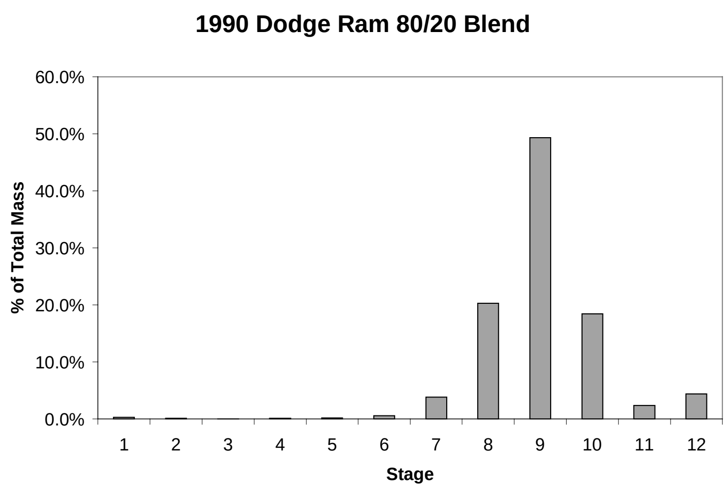


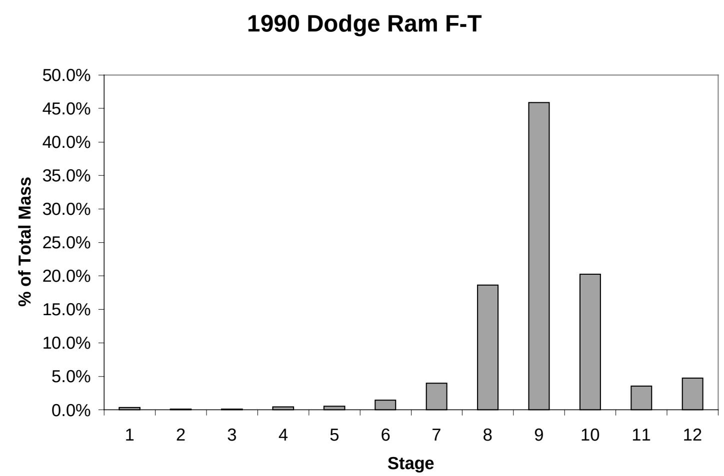


Appendix C2. cont. Composite MOUDI Spectra for 1990 Dodge Ram

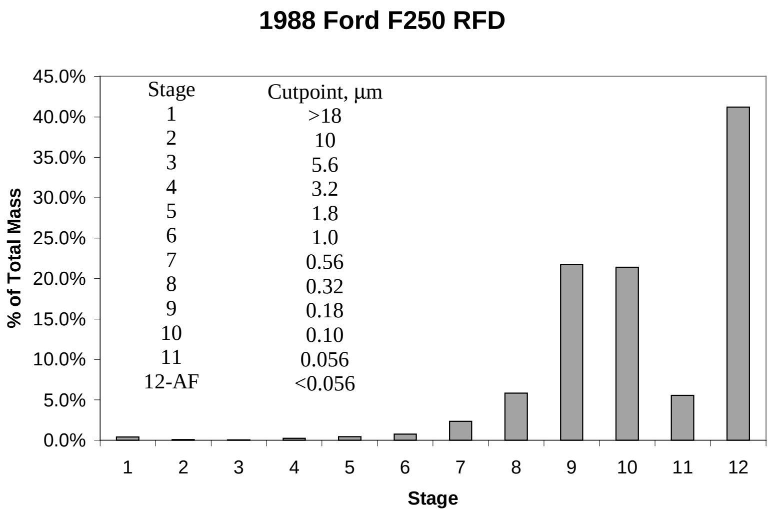


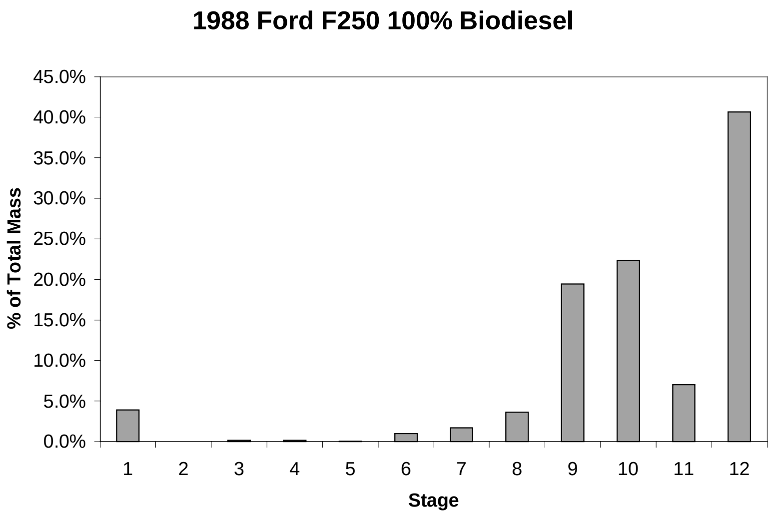


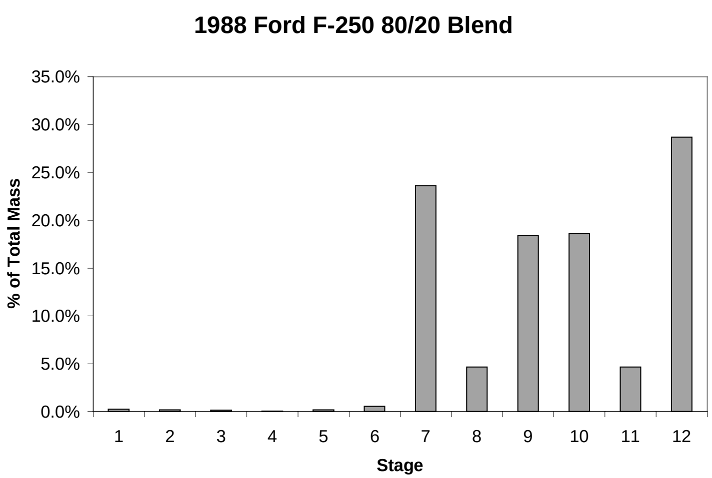


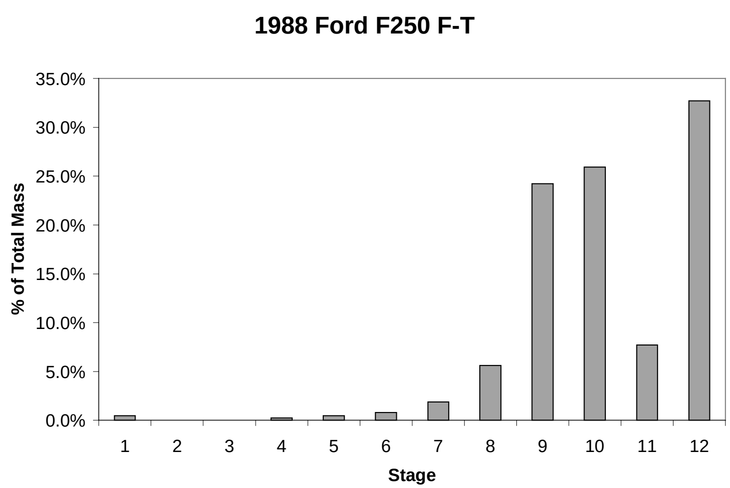


Appendix C2. cont. Composite MOUDI Spectra for 1988 Ford F250









Appendix D. FTP PM Composition for 1996 Dodge (mg/mi)

Vehicle	96 Dodge			96 Dodge			96 Dodge			96 Dodge		
Fuel	**RFD**			**Fischer Tropsch**			**80/20 blend**			**100% BioD**		
FTP PM	74.0	+/-	2.5	79.7	+/-	2.4	52.6	+/-	2.0	63.6	+/-	2.3
OC	28.0	+/-	2.2	38.7	+/-	3.0	22.0	+/-	1.8	32.0	+/-	2.5
EC	29.0	+/-	1.0	31.8	+/-	1.1	23.3	+/-	0.8	18.6	+/-	0.6
TC	56.9	+/-	3.1	70.5	+/-	3.8	45.3	+/-	2.5	50.5	+/-	2.8
NO_3	-0.004	+/-	0.041	-0.004	+/-	0.040	0.153	+/-	0.042	0.143	+/-	0.042
SO_4	0.405	+/-	0.050	0.216	+/-	0.043	0.375	+/-	0.049	0.420	+/-	0.051
NH_4	0.132	+/-	0.045	0.088	+/-	0.044	0.083	+/-	0.045	0.112	+/-	0.045
Na	-0.064	+/-	0.109	0.003	+/-	0.095	-0.064	+/-	0.109	-0.014	+/-	0.119
Mg	-0.003	+/-	0.013	-0.012	+/-	0.012	-0.018	+/-	0.030	-0.031	+/-	0.038
Al	0.031	+/-	0.010	0.012	+/-	0.010	0.027	+/-	0.010	0.003	+/-	0.022
Si	0.281	+/-	0.012	0.105	+/-	0.008	0.215	+/-	0.011	0.195	+/-	0.010
P	0.025	+/-	0.006	0.023	+/-	0.005	0.038	+/-	0.006	0.070	+/-	0.006
S	0.296	+/-	0.010	0.185	+/-	0.008	0.232	+/-	0.009	0.251	+/-	0.009
Cl	0.030	+/-	0.009	0.021	+/-	0.008	0.087	+/-	0.010	0.123	+/-	0.010
K	-0.002	+/-	0.010	0.001	+/-	0.014	0.010	+/-	0.006	0.035	+/-	0.006
Ca	0.155	+/-	0.010	0.123	+/-	0.009	0.114	+/-	0.009	0.144	+/-	0.010
Ti	0.000	+/-	0.057	0.000	+/-	0.056	0.000	+/-	0.052	0.000	+/-	0.052
V	0.000	+/-	0.033	0.000	+/-	0.026	0.000	+/-	0.025	0.000	+/-	0.025
Cr	0.000	+/-	0.011	0.006	+/-	0.006	0.000	+/-	0.007	0.000	+/-	0.007
Mn	0.000	+/-	0.005	0.000	+/-	0.004	0.000	+/-	0.004	0.000	+/-	0.004
Fe	0.015	+/-	0.002	0.046	+/-	0.002	0.021	+/-	0.002	0.042	+/-	0.002
Co	0.000	+/-	0.002	0.000	+/-	0.003	0.000	+/-	0.002	0.000	+/-	0.003
Ni	0.000	+/-	0.002	0.000	+/-	0.003	0.000	+/-	0.002	0.000	+/-	0.002
Cu	0.000	+/-	0.003	0.000	+/-	0.003	0.012	+/-	0.002	0.014	+/-	0.002
Zn	0.121	+/-	0.004	0.099	+/-	0.003	0.203	+/-	0.006	0.330	+/-	0.010
Ga	0.000	+/-	0.004	0.000	+/-	0.004	0.000	+/-	0.004	0.000	+/-	0.004
As	0.002	+/-	0.006	0.000	+/-	0.005	0.002	+/-	0.005	0.001	+/-	0.006
Se	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.002	0.000	+/-	0.002
Br	0.002	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.002	0.003	+/-	0.002
Rb	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.002
Sr	0.001	+/-	0.002	0.000	+/-	0.003	0.000	+/-	0.002	0.000	+/-	0.002
Y	0.000	+/-	0.003	0.001	+/-	0.003	0.000	+/-	0.003	0.001	+/-	0.003
Zr	0.000	+/-	0.003	0.000	+/-	0.004	0.000	+/-	0.003	0.000	+/-	0.003
Mo	0.002	+/-	0.006	0.004	+/-	0.007	0.001	+/-	0.006	0.003	+/-	0.006
Pd	-0.001	+/-	0.016	-0.001	+/-	0.017	-0.001	+/-	0.016	-0.001	+/-	0.016
Ag	-0.002	+/-	0.020	-0.002	+/-	0.021	-0.002	+/-	0.019	-0.002	+/-	0.019
Cd	0.000	+/-	0.021	0.000	+/-	0.021	0.000	+/-	0.020	0.000	+/-	0.020
In	0.000	+/-	0.024	0.011	+/-	0.024	0.003	+/-	0.023	0.000	+/-	0.023
Sn	0.000	+/-	0.031	0.009	+/-	0.032	0.010	+/-	0.031	0.000	+/-	0.030
Sb	0.000	+/-	0.036	0.013	+/-	0.038	0.000	+/-	0.035	0.000	+/-	0.035
Ba	-0.052	+/-	0.126	-0.059	+/-	0.132	-0.059	+/-	0.122	-0.059	+/-	0.123
La	0.003	+/-	0.192	-0.075	+/-	0.197	-0.075	+/-	0.182	-0.075	+/-	0.183
Au	0.000	+/-	0.008	0.000	+/-	0.008	0.000	+/-	0.010	0.000	+/-	0.013
Hg	0.000	+/-	0.006	0.000	+/-	0.006	0.000	+/-	0.005	0.000	+/-	0.005
Tl	-0.001	+/-	0.005	0.000	+/-	0.006	-0.001	+/-	0.005	0.000	+/-	0.005
Pb	0.012	+/-	0.005	0.000	+/-	0.008	0.000	+/-	0.007	0.013	+/-	0.005
U	0.000	+/-	0.005	0.000	+/-	0.006	0.000	+/-	0.005	0.000	+/-	0.005

Appendix D. FTP PM Composition for 1995 Ford (mg/mi)

Vehicle Fuel	95 Ford RFD			95 Ford Fischer Tropsch			95 Ford 80/20 blend			95 Ford 100% BioD		
FTP PM	76.9	+/-	2.6	50.0	+/-	1.9	107.8	+/-	3.3	106.3	+/-	3.2
OC	39.5	+/-	3.0	26.5	+/-	2.1	56.8	+/-	4.2	64.6	+/-	4.8
EC	24.2	+/-	0.8	24.2	+/-	0.8	26.6	+/-	0.9	18.5	+/-	0.6
TC	63.7	+/-	3.4	50.6	+/-	2.8	83.4	+/-	4.4	83.1	+/-	4.4
NO_3	-0.004	+/-	0.040	0.266	+/-	0.042	0.076	+/-	0.040	-0.004	+/-	0.040
SO_4	0.451	+/-	0.052	0.170	+/-	0.042	0.526	+/-	0.055	0.279	+/-	0.045
NH_4	0.134	+/-	0.044	0.059	+/-	0.044	0.140	+/-	0.044	0.097	+/-	0.044
Na	-0.064	+/-	0.097	-0.064	+/-	0.093	-0.064	+/-	0.103	-0.064	+/-	0.139
Mg	-0.004	+/-	0.014	0.003	+/-	0.013	0.028	+/-	0.012	0.036	+/-	0.015
Al	0.010	+/-	0.010	0.007	+/-	0.010	-0.013	+/-	0.021	0.000	+/-	0.023
Si	0.170	+/-	0.009	0.103	+/-	0.008	0.160	+/-	0.009	0.089	+/-	0.008
P	0.049	+/-	0.006	0.031	+/-	0.005	0.045	+/-	0.006	0.148	+/-	0.008
S	0.270	+/-	0.010	0.101	+/-	0.006	0.260	+/-	0.010	0.137	+/-	0.007
Cl	0.041	+/-	0.009	0.019	+/-	0.008	0.057	+/-	0.009	0.081	+/-	0.010
K	0.007	+/-	0.006	-0.006	+/-	0.010	0.001	+/-	0.009	0.015	+/-	0.006
Ca	0.142	+/-	0.010	0.066	+/-	0.009	0.138	+/-	0.010	0.151	+/-	0.010
Ti	0.000	+/-	0.052	0.000	+/-	0.056	0.000	+/-	0.053	0.000	+/-	0.055
V	0.000	+/-	0.025	0.000	+/-	0.026	0.000	+/-	0.025	0.000	+/-	0.032
Cr	0.000	+/-	0.007	0.000	+/-	0.007	0.000	+/-	0.007	0.003	+/-	0.010
Mn	0.000	+/-	0.004	0.000	+/-	0.004	0.000	+/-	0.004	0.003	+/-	0.005
Fe	0.013	+/-	0.002	0.009	+/-	0.002	0.018	+/-	0.002	0.054	+/-	0.003
Co	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.003
Ni	0.000	+/-	0.002	0.000	+/-	0.003	0.000	+/-	0.002	0.000	+/-	0.002
Cu	0.001	+/-	0.003	0.000	+/-	0.003	0.009	+/-	0.002	0.023	+/-	0.002
Zn	0.122	+/-	0.004	0.074	+/-	0.003	0.159	+/-	0.005	0.427	+/-	0.012
Ga	0.000	+/-	0.004	0.000	+/-	0.004	0.000	+/-	0.004	0.000	+/-	0.004
As	0.000	+/-	0.005	0.001	+/-	0.005	0.001	+/-	0.006	0.002	+/-	0.019
Se	0.000	+/-	0.002	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003
Br	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.002	-0.001	+/-	0.002
Rb	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.002
Sr	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.002	0.001	+/-	0.002
Y	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003
Zr	0.000	+/-	0.003	0.000	+/-	0.004	0.000	+/-	0.003	0.000	+/-	0.003
Mo	0.000	+/-	0.006	0.000	+/-	0.007	0.000	+/-	0.006	0.000	+/-	0.006
Pd	0.003	+/-	0.016	-0.001	+/-	0.017	-0.001	+/-	0.016	0.000	+/-	0.016
Ag	-0.002	+/-	0.019	-0.002	+/-	0.021	-0.002	+/-	0.020	-0.002	+/-	0.020
Cd	0.000	+/-	0.020	0.000	+/-	0.021	0.000	+/-	0.021	0.000	+/-	0.020
In	0.005	+/-	0.023	0.000	+/-	0.025	0.000	+/-	0.023	0.000	+/-	0.023
Sn	0.015	+/-	0.031	0.000	+/-	0.033	0.006	+/-	0.031	0.000	+/-	0.031
Sb	0.000	+/-	0.035	0.001	+/-	0.038	0.007	+/-	0.036	0.000	+/-	0.036
Ba	0.008	+/-	0.122	0.005	+/-	0.131	0.005	+/-	0.124	-0.040	+/-	0.123
La	-0.032	+/-	0.183	-0.060	+/-	0.197	-0.075	+/-	0.185	-0.012	+/-	0.185
Au	0.000	+/-	0.008	0.000	+/-	0.008	0.000	+/-	0.009	0.000	+/-	0.016
Hg	0.000	+/-	0.005	0.000	+/-	0.006	0.000	+/-	0.005	0.000	+/-	0.006
Tl	-0.001	+/-	0.005	-0.001	+/-	0.006	-0.001	+/-	0.005	0.000	+/-	0.006
Pb	0.007	+/-	0.005	0.000	+/-	0.008	0.020	+/-	0.005	0.113	+/-	0.006
U	0.000	+/-	0.005	0.000	+/-	0.006	0.000	+/-	0.005	0.000	+/-	0.005

Appendix D. FTP PM Composition for 1990 Dodge (mg/mi)

Vehicle	90 Dodge			90 Dodge			90 Dodge			90 Dodge		
Fuel	**RFD**			**Fischer Tropsch**			**80/20 blend**			**100% BioD**		
FTP PM	180.9	+/-	6.7	314.2	+/-	8.5	455.7	+/-	13.5	872.0	+/-	28.5
OC	93.0	+/-	6.8	147.5	+/-	10.6	268.0	+/-	19.1	436.9	+/-	30.9
EC	84.1	+/-	2.8	112.6	+/-	3.7	103.8	+/-	3.4	56.6	+/-	1.9
TC	177.1	+/-	9.2	260.2	+/-	13.4	371.8	+/-	19.1	493.5	+/-	25.4
NO_3	0.422	+/-	0.087	0.168	+/-	0.044	0.256	+/-	0.042	-0.004	+/-	0.040
SO_4	1.181	+/-	0.119	0.203	+/-	0.046	1.429	+/-	0.109	0.029	+/-	0.040
NH_4	0.537	+/-	0.088	0.141	+/-	0.047	0.626	+/-	0.048	0.225	+/-	0.045
Na	0.162	+/-	0.076	-0.011	+/-	0.117	-0.064	+/-	0.116	-0.064	+/-	0.143
Mg	0.034	+/-	0.025	-0.006	+/-	0.043	-0.044	+/-	0.041	-0.042	+/-	0.043
Al	0.048	+/-	0.015	-0.004	+/-	0.025	0.012	+/-	0.011	-0.003	+/-	0.027
Si	0.438	+/-	0.020	0.300	+/-	0.013	0.350	+/-	0.015	0.310	+/-	0.014
P	0.054	+/-	0.009	0.029	+/-	0.006	0.046	+/-	0.007	0.101	+/-	0.007
S	0.754	+/-	0.025	0.233	+/-	0.009	0.835	+/-	0.025	0.538	+/-	0.017
Cl	0.025	+/-	0.031	0.024	+/-	0.009	0.048	+/-	0.011	0.165	+/-	0.012
K	0.004	+/-	0.018	-0.001	+/-	0.012	-0.002	+/-	0.014	0.060	+/-	0.007
Ca	0.128	+/-	0.012	0.088	+/-	0.010	0.110	+/-	0.009	0.154	+/-	0.010
Ti	0.000	+/-	0.109	0.000	+/-	0.066	0.000	+/-	0.056	0.000	+/-	0.066
V	0.000	+/-	0.063	0.000	+/-	0.029	0.000	+/-	0.026	0.000	+/-	0.038
Cr	0.000	+/-	0.020	0.000	+/-	0.008	0.002	+/-	0.007	0.000	+/-	0.012
Mn	0.000	+/-	0.009	0.000	+/-	0.005	0.000	+/-	0.004	0.000	+/-	0.005
Fe	0.009	+/-	0.002	0.017	+/-	0.002	0.028	+/-	0.002	0.103	+/-	0.004
Co	0.001	+/-	0.004	0.000	+/-	0.003	0.000	+/-	0.002	0.000	+/-	0.003
Ni	0.002	+/-	0.004	0.000	+/-	0.003	0.000	+/-	0.002	0.000	+/-	0.003
Cu	0.000	+/-	0.005	0.000	+/-	0.003	0.004	+/-	0.002	0.008	+/-	0.002
Zn	0.085	+/-	0.004	0.081	+/-	0.003	0.148	+/-	0.005	0.318	+/-	0.009
Ga	0.000	+/-	0.008	0.000	+/-	0.005	0.000	+/-	0.004	0.000	+/-	0.005
As	0.000	+/-	0.010	0.000	+/-	0.006	0.004	+/-	0.005	0.001	+/-	0.007
Se	0.000	+/-	0.005	0.001	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003
Br	0.000	+/-	0.005	0.001	+/-	0.003	0.001	+/-	0.003	0.004	+/-	0.002
Rb	0.000	+/-	0.004	0.001	+/-	0.003	0.000	+/-	0.002	0.001	+/-	0.002
Sr	0.001	+/-	0.005	0.003	+/-	0.002	0.000	+/-	0.002	0.002	+/-	0.003
Y	0.002	+/-	0.006	0.003	+/-	0.002	0.000	+/-	0.003	0.002	+/-	0.003
Zr	0.000	+/-	0.007	0.001	+/-	0.004	0.000	+/-	0.004	0.002	+/-	0.004
Mo	0.000	+/-	0.013	0.000	+/-	0.008	0.000	+/-	0.007	0.000	+/-	0.007
Pd	-0.001	+/-	0.032	-0.001	+/-	0.020	0.000	+/-	0.017	-0.001	+/-	0.018
Ag	-0.002	+/-	0.038	-0.002	+/-	0.024	-0.002	+/-	0.020	-0.002	+/-	0.022
Cd	0.000	+/-	0.040	0.000	+/-	0.025	0.000	+/-	0.021	0.000	+/-	0.022
In	0.010	+/-	0.046	0.000	+/-	0.028	0.013	+/-	0.024	0.001	+/-	0.026
Sn	0.000	+/-	0.059	0.022	+/-	0.037	0.006	+/-	0.032	0.008	+/-	0.035
Sb	0.003	+/-	0.070	0.000	+/-	0.044	0.000	+/-	0.038	0.000	+/-	0.041
Ba	-0.059	+/-	0.243	-0.059	+/-	0.158	0.023	+/-	0.132	0.010	+/-	0.145
La	0.079	+/-	0.365	-0.075	+/-	0.234	-0.052	+/-	0.197	0.049	+/-	0.220
Au	0.000	+/-	0.014	0.000	+/-	0.009	0.000	+/-	0.009	0.000	+/-	0.014
Hg	0.000	+/-	0.011	0.000	+/-	0.007	0.000	+/-	0.006	0.000	+/-	0.006
Tl	-0.001	+/-	0.010	0.002	+/-	0.007	-0.001	+/-	0.006	-0.001	+/-	0.006
Pb	0.000	+/-	0.014	0.000	+/-	0.009	0.001	+/-	0.008	0.021	+/-	0.005
U	0.000	+/-	0.010	0.002	+/-	0.007	0.000	+/-	0.006	0.000	+/-	0.006

Appendix D. FTP PM Composition for 1988 Ford (mg/mi)

Vehicle	88 Ford			88 Ford			88 Ford			88 Ford		
Fuel	**RFD**			**Fischer Tropsch**			**80/20 blend**			**100% BioD**		
FTP PM	396.8	+/-	13.2	385.8	+/-	11.0	464.3	+/-	13.2	451.2	+/-	14.6
OCTC	296.2	+/-	21.0	291.1	+/-	20.7	320.1	+/-	22.7	363.1	+/-	25.7
ECTC	52.9	+/-	1.7	44.1	+/-	1.5	54.7	+/-	1.8	34.9	+/-	1.2
TCTC	349.1	+/-	18.0	335.3	+/-	17.3	374.8	+/-	19.3	398.0	+/-	20.5
NO3	0.164	+/-	0.044	0.432	+/-	0.045	0.156	+/-	0.041	0.694	+/-	0.051
SO4	0.845	+/-	0.074	0.137	+/-	0.042	0.848	+/-	0.073	0.385	+/-	0.048
NH4	0.499	+/-	0.049	0.248	+/-	0.045	0.451	+/-	0.047	0.240	+/-	0.044
NA	-0.064	+/-	0.241	-0.064	+/-	0.180	-0.064	+/-	0.220	-0.064	+/-	0.277
MG	-0.040	+/-	0.056	-0.046	+/-	0.044	-0.006	+/-	0.052	0.008	+/-	0.019
AL	-0.001	+/-	0.033	-0.009	+/-	0.028	0.010	+/-	0.032	0.025	+/-	0.013
SI	0.167	+/-	0.012	0.143	+/-	0.010	0.177	+/-	0.012	0.123	+/-	0.011
P	0.374	+/-	0.015	0.289	+/-	0.012	0.399	+/-	0.015	0.498	+/-	0.017
S	1.275	+/-	0.038	0.543	+/-	0.017	1.258	+/-	0.037	0.731	+/-	0.023
CL	0.081	+/-	0.014	0.091	+/-	0.011	0.050	+/-	0.013	0.122	+/-	0.013
K	-0.006	+/-	0.015	-0.006	+/-	0.012	0.005	+/-	0.014	0.180	+/-	0.010
CA	0.963	+/-	0.030	0.740	+/-	0.024	0.904	+/-	0.028	1.045	+/-	0.032
TI	0.000	+/-	0.063	0.000	+/-	0.056	0.000	+/-	0.057	0.000	+/-	0.062
V	0.000	+/-	0.028	0.000	+/-	0.026	0.000	+/-	0.026	0.000	+/-	0.028
CR	0.001	+/-	0.008	0.003	+/-	0.007	0.008	+/-	0.006	0.011	+/-	0.006
MN	0.000	+/-	0.005	0.000	+/-	0.004	0.000	+/-	0.004	0.005	+/-	0.003
FE	0.047	+/-	0.002	0.040	+/-	0.002	0.063	+/-	0.003	0.272	+/-	0.008
CO	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.005
NI	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003
CU	0.006	+/-	0.002	0.000	+/-	0.003	0.005	+/-	0.002	0.018	+/-	0.002
ZN	0.839	+/-	0.024	0.610	+/-	0.018	0.803	+/-	0.023	1.079	+/-	0.031
GA	0.000	+/-	0.005	0.000	+/-	0.004	0.000	+/-	0.005	0.000	+/-	0.005
AS	0.000	+/-	0.007	0.000	+/-	0.005	0.003	+/-	0.006	0.002	+/-	0.009
SE	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003
BR	0.001	+/-	0.003	0.000	+/-	0.002	-0.001	+/-	0.003	0.002	+/-	0.002
RB	0.001	+/-	0.003	0.000	+/-	0.002	0.000	+/-	0.002	0.000	+/-	0.003
SR	0.006	+/-	0.002	0.003	+/-	0.002	0.005	+/-	0.002	0.006	+/-	0.002
Y	0.001	+/-	0.003	0.000	+/-	0.003	0.000	+/-	0.003	0.001	+/-	0.004
ZR	0.001	+/-	0.004	0.000	+/-	0.004	0.000	+/-	0.004	0.001	+/-	0.004
MO	0.000	+/-	0.008	0.000	+/-	0.007	0.000	+/-	0.007	0.000	+/-	0.008
PD	-0.001	+/-	0.018	-0.001	+/-	0.017	-0.001	+/-	0.017	-0.001	+/-	0.018
AG	0.004	+/-	0.022	-0.002	+/-	0.020	-0.002	+/-	0.021	-0.002	+/-	0.022
CD	0.000	+/-	0.023	0.000	+/-	0.021	0.000	+/-	0.021	0.000	+/-	0.023
IN	0.000	+/-	0.026	0.000	+/-	0.024	0.000	+/-	0.024	0.000	+/-	0.027
SN	0.017	+/-	0.036	0.000	+/-	0.032	0.009	+/-	0.033	0.004	+/-	0.036
SB	0.011	+/-	0.042	0.000	+/-	0.037	0.004	+/-	0.038	0.000	+/-	0.042
BA	0.035	+/-	0.148	0.012	+/-	0.132	-0.059	+/-	0.135	-0.049	+/-	0.147
LA	-0.050	+/-	0.222	-0.037	+/-	0.198	-0.036	+/-	0.203	-0.037	+/-	0.222
AU	0.000	+/-	0.030	0.000	+/-	0.022	0.000	+/-	0.029	0.000	+/-	0.037
HG	0.000	+/-	0.007	0.000	+/-	0.006	0.000	+/-	0.007	0.000	+/-	0.007
TL	0.001	+/-	0.006	-0.001	+/-	0.006	-0.001	+/-	0.006	0.000	+/-	0.007
PB	0.018	+/-	0.005	0.000	+/-	0.008	0.008	+/-	0.005	0.041	+/-	0.005
U	0.003	+/-	0.006	0.000	+/-	0.006	0.000	+/-	0.006	0.002	+/-	0.006

Appendix E1. Semi-volatile PAH Results

Vehicle Fuel	88 Ford RFD mg/mi	88 Ford Fischer-T. Mg/mi	88 Ford 80/20 mg/mi	88 Ford 100% BioD mg/mi	Uncert mg/mi
FTP PM	396.8	385.8	464.3	451.2	
OCTC	296.2	291.1	320.1	363.1	
ECTC	52.9	44.1	54.7	34.9	
TCTC	349.1	335.3	374.8	398.0	
Total PAH	**0.816**	**1.017**	**0.975**	**0.831**	0.068
Naphthalene	**0.308**	**0.468**	**0.479**	**0.410**	0.041
2-Menaphthalene	**0.069**	**0.077**	**0.062**	**0.088**	0.014
1-Menaphthalene	**0.060**	**0.068**	**0.063**	**0.080**	0.011
Biphenyl	**0.021**	**0.023**	**0.028**	**0.022**	0.007
2-Ethyl-1-methylnaphthalene	**0.011**	**0.016**	**0.015**	**0.011**	0.005
2,6+2,7-Dimenaphthalene	0.010	0.016	0.012	0.011	0.013
1,7+1,3+1,6-Dimenaphthalene	0.032	**0.039**	**0.036**	0.027	0.017
2,3+1,4+1,5-Dimenaphthalene	0.004	0.008	0.008	0.006	0.024
1,2-Dimenaphthalene	0.001	0.003	0.005	0.005	0.015
1,8-Dimenaphthalene	0.001	0.000	0.000	0.000	0.012
2-Methylbiphenyl	**0.032**	**0.057**	**0.024**	0.003	0.007
3-Methylbiphenyl	**0.042**	**0.034**	**0.041**	0.009	0.007
4-Methylbiphenyl	**0.015**	**0.019**	**0.020**	**0.008**	0.003
A-Trimethylnaphthalene	**0.007**	**0.007**	**0.007**	**0.006**	0.003
1-Ethyl-2-methylnaphthalene	0.002	0.004	0.001	0.004	0.002
B-Trimethylnaphthalene	**0.008**	**0.009**	**0.007**	**0.007**	0.002
C-Trimethylnaphthalene	**0.006**	**0.008**	0.004	**0.007**	0.002
2-Ethyl-1-methylnaphthalene	0.000	0.000	0.000	0.000	0.002
E-Trimethylnaphthalene	**0.005**	**0.006**	0.004	**0.005**	0.002
F-Trimethylnaphthalene	**0.013**	**0.008**	**0.009**	**0.007**	0.002
2,3,5+I-Trimethylnaphthalene	**0.010**	**0.008**	**0.007**	**0.006**	0.002
2,4,5 Trimethylnaphthalene	0.003	0.003	0.004	0.002	0.002
J-Trimethylnaphthalene	0.001	0.003	0.001	0.000	0.003
1,4,5-Trimethylnaphthalene	0.000	0.000	0.000	0.000	0.002
1,2,8-Trimethylnaphthalene	0.003	0.004	0.000	0.004	0.002
Acenaphthylene	**0.030**	**0.037**	0.027	**0.043**	0.014
Acenaphthene	0.003	0.002	0.004	0.004	0.007
Fluorene	**0.018**	**0.019**	**0.018**	**0.015**	0.007
Phenanthrene	**0.031**	**0.016**	**0.014**	**0.011**	0.004
A-Methylfluorene	**0.005**	**0.006**	0.004	0.002	0.002
1-Methylfluorene	0.006	0.002	**0.011**	0.003	0.004
B-Methylfluorene	0.001	0.001	0.001	0.001	0.003
A-Methylphenanthrene	**0.010**	0.005	**0.006**	0.005	0.003
2-Methylphenanthrene	**0.013**	**0.008**	**0.007**	**0.007**	0.002

Appendix E1. Semi-volatile PAH Results (CONTINUED)

Vehicle Fuel	88 Ford RFD mg/mi	88 Ford Fischer-T. mg/mi	88 Ford 80/20 mg/mi	88 Ford 100% BioD mg/mi	Uncert. mg/mi
B-Methylphenanthrene	0.000	0.000	0.000	0.000	0.002
C-Methylphenanthrene	0.002	0.000	0.001	0.000	0.003
1-Methylphenanthrene	0.004	0.003	0.002	0.001	0.002
Anthrone	0.003	0.001	0.004	0.007	0.005
Anthraquinone	0.002	0.003	0.006	-0.001	0.003
3,6-Dimethylphenanthrene	0.000	0.001	0.000	0.000	0.002
A-Dimethylphenanthrene	0.002	0.001	0.001	0.000	0.002
B-Dimethylphenanthrene	0.000	0.001	0.000	0.000	0.002
C-Dimethylphenanthrene	0.002	0.003	0.001	0.002	0.002
1,7-Dimethylphenanthrene	0.001	0.000	0.000	0.001	0.002
D-Dimethylphenanthrene	0.000	0.000	0.000	0.000	0.002
E-Dimethylphenanthrene	0.000	0.000	0.000	0.000	0.002
Anthracene	0.007	0.010	0.013	0.004	0.009
9-Methylanthracene	0.000	0.000	0.002	0.000	0.002
Fluoranthene	0.005	0.002	0.001	0.000	0.005
Pyrene	0.006	0.005	0.004	0.002	0.003
Retene	0.000	0.000	0.000	0.000	0.003
Benzonaphthotiophene	0.000	0.000	0.000	0.000	0.004
A- Methylpyrene/methylfluoranthene	0.001	-0.001	0.001	-0.001	0.002
B- Methylpyrene/methylfluoranthene	0.000	0.000	0.000	0.000	0.002
C- Methylpyrene/methylfluoranthene	0.000	0.000	0.000	0.000	0.002
D- Methylpyrene/methylfluoranthene	0.000	0.000	0.000	0.000	0.002
4-Methylpyrene	0.000	0.000	0.000	0.000	0.002
1-Methylpyrene	0.000	0.000	0.000	0.000	0.002
Benz(a)anthracene	-0.001	0.000	-0.001	-0.001	0.007
7-Methylbenz[a]anthracene	0.000	0.000	0.000	0.000	0.002
Chrysene	0.000	0.001	0.000	0.000	0.003
Benzo(b+j+k)FL	0.001	0.000	0.000	0.000	0.004
7-Methylbenzo[a]pyrene	0.001	0.000	0.000	0.000	0.002
Benzo(e)pyrene	0.000	0.000	0.000	0.000	0.002
Benzo(a)pyrene	0.001	0.001	0.008	0.000	0.008
Indeno[123-cd]Pyrene	0.000	0.000	0.000	0.000	0.007
Benzo(ghi)Perylene	0.000	0.000	0.000	0.000	0.008
Dibenz(ah+ac)anthracene	0.000	0.000	0.000	0.000	0.012
Benzo(b)chrysene	0.000	0.000	0.000	0.000	0.006
Coronene	0.000	0.000	0.000	0.000	0.002

*compound less than background excluded from total

Appendix E2. Particulate PAH Results

Vehicle Fuel	88 Ford RFD mg/mi	88 Ford Fischer-T. mg/mi	88 Ford 80/20 blend mg/mi	88 Ford 100% BioD mg/mi	Uncert mg/mi
FTP PM	396.8	385.8	464.3	451.2	
OCTC	296.2	291.1	320.1	363.1	
ECTC	52.9	44.1	54.7	34.9	
TCTC	349.1	335.3	374.8	398.0	
Total PAH	**0.193**	**0.166**	**0.204**	**0.219**	
Naphthalene*	-0.075	-0.089	-0.085	-0.085	0.008
2-Menaphthalene*	-0.163	-0.170	-0.171	-0.171	0.020
1-Menaphthalene*	-0.077	-0.077	-0.079	-0.079	0.010
Biphenyl	0.001	0.000	-0.002	-0.002	0.003
2-Ethyl-1-methylnaphthalene	0.000	0.000	0.000	0.000	0.002
2,6+2,7-Dimenaphthalene	0.000	0.000	0.000	0.000	0.012
1,7+1,3+1,6-Dimenaphthalene	0.000	0.002	0.000	0.000	0.016
2,3+1,4+1,5-Dimenaphthalene	0.000	0.001	0.000	0.000	0.023
1,2-Dimenaphthalene	0.000	0.001	0.000	0.000	0.014
1,8-Dimenaphthalene	0.000	-0.002	0.000	0.000	0.012
2-Methylbiphenyl	0.000	0.001	0.000	0.000	0.002
3-Methylbiphenyl	0.000	0.000	-0.001	-0.001	0.002
4-Methylbiphenyl	0.001	0.001	0.000	0.000	0.002
A-Trimethylnaphthalene	0.000	0.001	0.000	0.000	0.002
1-Ethyl-2-methylnaphthalene	0.001	0.000	0.002	0.003	0.002
B-Trimethylnaphthalene	0.000	0.001	0.000	0.000	0.002
C-Trimethylnaphthalene	0.000	0.000	0.000	0.000	0.002
2-Ethyl-1-methylnaphthalene	0.000	0.000	0.000	0.000	0.002
E-Trimethylnaphthalene	0.000	0.000	0.000	0.000	0.002
F-Trimethylnaphthalene	0.000	0.000	0.000	0.000	0.002
2,3,5,+I-Trimethylnaphthalene	0.001	-0.001	0.000	0.000	0.002
2,4,5-Trimethylnaphthalene	0.000	0.000	0.000	0.000	0.002
J-Trimethylnaphthalene	0.000	0.001	0.000	0.000	0.002
1,4,5-Trimethylnaphthalene	0.000	0.002	0.000	0.000	0.002
1,2,8-Trimethylnaphthalene	0.000	0.000	0.000	0.000	0.002
Acenaphthylene	0.001	0.001	0.001	0.001	0.014
Acenaphthene	0.000	0.008	0.000	0.000	0.006
Fluorene	0.001	-0.001	0.000	0.001	0.003
Phenanthrene	**0.010**	**0.008**	**0.009**	**0.011**	0.002
A-Methylfluorene	0.000	-0.001	0.000	-0.001	0.002
1-Methylfluorene	0.002	0.000	0.001	0.001	0.002
B-Methylfluorene	0.000	0.000	0.000	0.000	0.002
A-Methylphenanthrene	**0.011**	**0.010**	**0.014**	**0.019**	0.003
2-Methylphenanthrene	**0.016**	**0.012**	**0.018**	**0.019**	0.002

*compound less than background excluded from total

Appendix E2 Particulate PAH Results (CONTINUED)

Vehicle **Fuel**	**88 Ford** **RFD** **mg/mi**	**88 Ford** **Fischer-T.** **mg/mi**	**88 Ford** **80/20 blend** **mg/mi**	**88 Ford** **100% BioD** **mg/mi**	**Uncert** **mg/mi**
B-Methylphenanthrene	0.000	0.002	0.001	0.000	0.002
C-Methylphenanthrene	**0.005**	0.004	**0.006**	**0.006**	0.003
1-Methylphenanthrene	**0.009**	0.004	**0.008**	**0.007**	0.002
Anthraquinone	0.003	-0.001	0.003	0.004	0.003
3,6-Dimethylphenanthrene	0.007	0.005	0.008	0.007	0.009
A-Dimethylphenanthrene	**0.011**	**0.013**	**0.011**	**0.013**	0.003
B-Dimethylphenanthrene	**0.005**	**0.012**	**0.008**	**0.005**	0.003
C-Dimethylphenanthrene	0.016	0.000	**0.021**	**0.017**	0.008
1,7-Dimethylphenanthrene	**0.009**	**0.009**	**0.009**	**0.009**	0.004
D-Dimethylphenanthrene	**0.007**	**0.006**	**0.006**	**0.004**	0.002
E-Dimethylphenanthrene	**0.006**	**0.009**	**0.007**	**0.007**	0.003
Anthracene	0.002	0.002	0.001	0.000	0.002
9-Methylanthracene	0.000	0.000	0.000	0.000	0.002
Fluoranthene	0.006	0.009	0.011	**0.023**	0.006
Pyrene	**0.033**	0.014	**0.026**	**0.032**	0.008
Retene	0.000	0.000	0.000	0.000	0.003
Benzonaphthotiophene	0.001	0.002	0.000	0.001	0.004
A- Methylpyrene/methylfluoranthene	0.001	0.002	0.001	-0.001	0.002
B- Methylpyrene/methylfluoranthene	0.002	0.000	0.001	0.002	0.003
C- Methylpyrene/methylfluoranthene	0.000	**0.007**	0.000	0.001	0.002
D- Methylpyrene/methylfluoranthene	0.010	0.000	0.010	0.008	0.006
4-Methylpyrene	**0.007**	0.005	**0.010**	**0.007**	0.003
1-Methylpyrene	0.000	0.004	**0.008**	**0.005**	0.003
Benz(a)anthracene	0.004	-0.001	0.002	0.005	0.007
7-Methylbenz[a]anthracene	0.000	0.000	0.000	0.000	0.002
Chrysene	0.004	0.000	0.003	0.004	0.003
Benzo(b+j+k)FL	0.001	0.000	0.001	0.001	0.004
7-Methylbenzo[a]pyrene	0.001	-0.002	0.000	0.001	0.002
Benzo(e)pyrene	0.001	-0.001	0.000	0.000	0.002
Benzo(a)pyrene	0.000	0.000	0.000	0.000	0.007
Indeno[123-cd]Pyrene	0.000	0.004	0.000	0.000	0.007
Benzo(ghi)Perylene	0.000	0.009	0.000	0.000	0.008
Dibenz(ah+ac)anthracene	0.000	0.001	0.000	0.000	0.012
Benzo(b)chrysene	0.000	0.000	0.000	0.000	0.006
Coronene	0.000	0.002	0.000	0.000	0.002

*compound less than background excluded from total